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AN EVALUATION OF THE HEIGHT VELOCITY DIAGRAM OF A LIGHTWEIGHT, LOW ROTOR INERTIA, SINGLE ENGINE HELICOPTER

TECHNICAL REPORT

JULY 1965

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FEDERAL AVIATION AGENCY
AIRCRAFT DEVELOPMENT SERVICE

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SUMMARY

A series of flight tests was conducted at three selected altitudes (sea level, 5000 feet, 7000 feet) to determine the effects of altitude and weight on the height-velocity (H-V) diagram of a small, lightweight, low rotor inertia, medium disk loading, single rotor, single engine helicopter. Two gross weights of the helicopter were used. Quantitative and qualitative test data were collected to determine how the H-V diagram varies with density altitude and aircraft gross weight. An investigation was made into the effects on the diagram of a delayed collective pitch application response.

Results disclosed a family of curves showing that increases in density altitude and/or gross weight enlarged the H-V diagram required for a safe power off landing. Analysis of the results revealed that the key points (V_{cr}, h_{min}, and h_{max}), which partially define the curves, could be determined by the solution of a set of linear equations. These results were identical to those reported in FAA Technical Report ADS-1 except for the constants of the linear equations and the location of the critical height (h_{cr}). The critical height indicated a slight increase as weight, altitude and collective pitch reduction time delay were increased. An average value for h_{cr} can be selected without upsetting the family of curves.

SYMBOLS

V_{cr}	=	critical velocity. The speed above which an autorotative landing can be made from any height after power failure in the low speed regime, mph, CAS.
h_{cr}	=	the height above the ground at which Vcr occurs, ft.
h_{min}	=	the high hover height - the height above the ground from above which a safe autorotative landing can be made after power failure at zero airspeed, ft.
h_{max}	=	the low hover height - the height above the ground from below which a safe power off landing can be made after power failure at zero airspeed, ft.
H_D	=	density altitude at the point of landing, ft.
h	=	height of the helicopter above the ground, ft.
W	=	helicopter weight, lb.
CAS	=	calibrated airspeed - indicated airspeed corrected for instrument and position error, mph.

INTRODUCTION

Purpose

The purpose of this project was to determine by flight tests the effects of altitude and weight on the height-velocity (H-V) diagrams of a small single-rotor helicopter which has an inherently low rotor inertia and medium disk loading.

Background

This flight test project is a continuation of a program initiated by the Aircraft Development Service, Federal Aviation Agency, to acquire sufficient actual flight test data on certain basic helicopter flight parameters associated with the determination of the H-V diagram. The ultimate objective of this program is to obtain a practical technical approach for the determination of the effects of altitude on the helicopter H-V diagram.

The H-V diagram is a chart which defines an envelope of flight with respect to airspeed and height above the ground where, in the event of power failure, a safe power off landing could not be effected. A typical H-V diagram as referred to in this report is shown in Fig. 1 and was established from steady-state level flight conditions.

The flight test project of this program as reported in Reference 1 was the first project undertaken to obtain flight test data on the power-off landing performance of a helicopter as the density altitude and gross weight are varied. The results of this project were successful in that the data were obtained and subsequent analysis disclosed that the H-V diagrams of the helicopter tested resolved into a family of curves as a function of weight and altitude. It was also concluded that this family of curves could be defined by empirical equations involving key points such as V_{cr}, h_{min} and h_{max} as shown in Fig. 1 in which h_{cr} appears to occur at a constant height above the ground. The sub-program scheduled additional testing utilizing two single rotor helicopters of widely different characteristics than the test vehicle used in Reference 1 in order to obtain an adequate data spread on helicopters of different characteristics.

The helicopter utilized for the tests reported herein generally represents one extreme in the spectrum of current single-engine helicopters with respect to gross weight, disk loading and rotor inertia considerations. The other extreme of the spectrum - a large, high gross-weight helicopter of high rotor inertia may be the target for future endeavor with a follow-on comprehensive study correlating the facts of all testing in this specific area of consideration.

DISCUSSION

Test Aircraft

The test vehicle was a small, lightweight, single rotor, single-engine helicopter as shown in Fig. 2. This aircraft was selected for this H-V test program because of its relatively low rotor inertia and medium disk loading. Pertinent specifications of this aircraft are presented in Appendix 1.

Test Instrumentation

Airborne and ground instrumentation was utilized to record helicopter performance and meteorological data. Details of the quantitative information measured and the equipment utilized are presented in Appendix 1.

Test Operations and Procedures

1. Flight Test Sites

The flight test project was conducted at three centrally located test sites in the State of California during the period from October 6, 1965, through December 8, 1965. These test sites, selected for their elevation and test environment, were as follows:

Fresno Municipal Airport	Elevation 332 ft. MSL
Bishop Municipal	Elevation 4118 ft. MSL
Long Valley Landing Strip	Elevation 7120 ft. MSL

A schematic view of the test site layout showing the relative locations of the test course, space positioning equipment, central markers and meteorological equipment used for the flight tests is shown in Fig. 3.

2. Test Methodology

A professional engineering test pilot well skilled in the mechanics of determining H-V diagrams was utilized for the flying function. The results of his airwork are therefore not representative of average pilot capabilities.

A total of 420 test runs were conducted to determine H-V diagrams at the selected test altitudes for gross weight conditions of 1450 and 1600 pounds.

The following is a general description of how the tests were conducted:

a. General

The pilot would fly over the test course at a specific steady airspeed at a given entry height above the ground and execute a simulated power failure by sudden retardation of the throttle to fully

disengage the rotor clutch. From this point he would land the aircraft with the power off. This procedure was repeated with the pilot adjusting his height or airspeed until he reached a point below which he felt a safe landing could not be made because all usable energy had been utilized. This point was then plotted as a point on the H-V diagram. The validity of his judgment was verified by means of limited on-site data reduction.

The above procedure was repeated until a sufficiency of points from which to generate an H-V diagram had been obtained.

b Collective Pitch Control Application

The usual procedure when power fails in flight with a single engine helicopter is for the pilot to retain the highest possible rotor speed to effect a landing. This is accomplished by immediate full reduction of the rotor blade pitch angle by means of the collective pitch stick control when the height above the ground is adequate. When the height above the ground and the consequent time differential between power failure and touchdown is limited, it is not always possible to effect full collective pitch reductions. In such cases, the pilot makes partial collective pitch reductions or simply utilizes what collective pitch he has remaining as the situation dictates. The fact that the test vehicle had inherently low rotor inertia prompted an investigation into the effects of a no-delay and one-second delay response in reducing collective pitch following throttle cut. It was anticipated that an observable step would be apparent at the "knee" of the curve but it was not certain whether this effect would "wash-out" at the heights approaching the high hover. Tests using a one-second delay response with collective pitch application were therefore programmed in addition to the no-delay technique.

3. Test Criteria

a. Rotor Speed

In order to eliminate as many variables as possible, the rotor speed in steady state autorotation was kept constant by adjusting the low pitch blade angle at each altitude tested. This involved raising the low pitch setting slightly at each test altitude by changing the length of the pitch link. Total collective pitch travel, therefore, was always available for control purposes.

b. Pilot Procedures

There were no restrictions placed on horizontal touchdown velocity; that is, the pilot was not instructed to obtain minimum touchdown speed, nor was he limited as to his maximum touchdown speed. The specific piloting techniques for handling the helicopter were left to the

discretion of the pilot. The only limitations in technique imposed upon the pilot were that of the no-delay and one-second delay in collect pitch reduction after throttle cut.

The decision as to whether a landing was a maximum performance effort was made by the pilot. His evaluation was based on whether he believed he had any usable reserve energy remaining in the form of rotor speed or airspeed, and the nature and magnitude of the impact.

The pilot's qualitative comments on techniques utilized and the related criteria for his decisions were used in evaluating the fligh test data. A discussion of these techniques can be found under "Pilot's Comments" in Appendix 2.

c. Weight Control

Weight was kept within approximately ± 1/2 percent by addir ballast after every few runs and refueling as required.

d. Wind Allowables

Limitations were placed on allowable wind velocities for these tests. The wind velocities were measured at a 12 ft. instrumentation height. Hovering and very slow speed tests were not conducted in wind velocities in excess of 2 mph, and all other tests were discontinu when the wind exceeded 5 mph at this height. A helium filled balloon moored so its height could be varied was utilized as a visual indicator wind aloft for the benefit of the pilot.

e. Altitude Control

All weights at each test site were tested over a common range of density altitude which was within approximately 600 feet of th average density altitude for each condition. It was considered that small variations in density altitude would have little effect on the test data results.

f. Entry Speeds and Conditions

All speeds used in the program and in this report are give in terms of calibrated airspeeds (CAS). The entry airspeed used for ea point on the H-V diagram was obtained from the photographic record as ground speed, corrected for observed wind at the 12 foot level and converted to calibrated airspeed.

ANALYSIS AND RESULTS

Discussion of Tests

A brief discussion of several aspects of the test program would appear to be in order at this point in order to enhance understanding of the test results. The test vehicle, which was small and light, was quite sensitive to the effects of wind, particularly in the very low speed regimes. Although test runs which exhibited crosswind components in excess of 3-4 mph were discarded, it is believed that some runs were affected which had crosswind components of small magnitude. The pilot reported having difficulty with some points which had a positive headwind component, but which were of the crosswind type.

Since one of the problems the pilot had to contend with in this type of test program was his ability to duplicate height-above-the-ground, a radar altimeter was installed with an accuracy that would provide the pilot with the degree of repeatability desired. The use of the radar altimeter introduced other problems, however. The altimeter was so sensitive to terrain irregularities, that in an effort to hold a constant height, the pilot frequently had to adjust the collective pitch setting, often at the last moment before throttle cut, thereby changing the entry power. Because of the power change, a commensurate change in ship attitude frequently occured.

The problem of correct airspeed indication to the pilot in the low airspeed regime was of particular significance in this program. The pilot was frequently unable to determine his airspeed accurately. A car pace was used in an effort to guide the pilot, but such things often tended to distract him from other requirements of stabilized flight at entry. The records indicate the calibrated airspeeds as determined by the pitot-static system and recorded on the oscillograph was unuseable below speeds of 30 mph.

Obtaining high hover and near high hover data was one of the most difficult parts of the test program. Unstable air conditions, unknown wind conditions aloft, indeterminate airspeeds and thus attitude variations all contributed to the difficulty. In general, weather conditions prevailing at the test sites during the conduct of the project were not particularly stable. It was frequently difficult to obtain continuous low wind velocities.

Height-Velocity Diagrams

Height-velocity diagrams were first constructed from the experimentally obtained data points. Various cross plots of velocity, altitude, weight and height-above-the-ground were then constructed and studied to determine what kind of relationships, if any, existed between the many H-V diagrams. Information from these cross plots was then used to adjust the original fairings of the height-velocity curves so that the curves then obtained provided the best fit with the data points and cross plotted points. The results herein presented exhibit linear relationships which are quite similar to those obtained from the testing reported in Reference 1. Since the test helicopter was quite small and utilized a sea level engine, the number of weights and altitudes at which it was possible to obtain data was restricted, thus somewhat complicating the ability to establish a confirmed relationship. These adjusted curves with experimental data points are shown in Figs. 4 and 5. The variation with altitude and gross weight is shown in Fig. for both no-delay and one-second delay conditions. The variation with altitude for each of the two gross weights is shown in Fig. 7. The variation with gross weight for the density altitudes tested is shown in Fig. 8.

Since the density altitude spread for all the runs at any given test site was larger than desired, an average density altitude for each condition of weight and collective pitch application was derived and utilized to facilitate data analysis. Test points could not be qualifie with respect to their relative position about an H-V curve in accordance with their test density altitude; i.e., outside the curve for higher altitude and inside the curve for lower altitude. Other variables which had much greater effect on the data overshadowed the altitude variation effects.

One exception to the data pattern developed in the 1600 lb. no-dela curve. This data showed a height-velocity diagram at sea level which gave a critical velocity which was two and a half mph too low, whereas the same data at 5000 feet showed a critical velocity which was one mph too high when referred to the rest of the data obtained. The 1450 lb. data with no-delay and one-second delay, as well as the 1600 lb. one-second delay data, checked out to provide plots of airspeed vs altitude and airspeed vs weight which agreed and conformed to the patter Further, the 1600 lb. no-delay data checked out in the low hover regime. The dotted lines on Fig. 5 indicate where these H-V diagrams would have been if these tests had been consistent with the rest of the data. This exception and deviation led to consideration of and investigation into drag divergence possibilities. It was concluded, however, that these small deviations are part of the scatter band of data which existed in the project.

The data contained in Table I is a summary chart of the pertinent facts taken from the time histories relative to all of the high hover and near high hover points. In all cases of high hover or near high hover, stabilizing of the autorotative descent was instituted within 25 to 35 feet of descent following throttle chop. That is to say, aft longitudinal stick was applied so that the aircraft started to arrest its nose down attitude, and in a very gradual manner this was continued so that maximum nose-up attitude occurred approximately two seconds prior to touchdown regardless of the initial height above the ground. The touchdown speeds (V_{TD}) appear to be of the same order of magnitude independent of altitude and weight when the entry is approximately at high hover. There appeared to be an increase in the touchdown speeds as the entry speeds increased but this was not consistent for the points in the area of the critical speed (V_{cr}) and critical height (h_{cr}). The vertical descent velocity following simulated power failure from high hover or near high hover increases as weight and density altitude increase. The rates of descent listed in Table I were the maximum rates of descent obtained and are considered stabilized rates of descent. These maximum rates of descent occurred on an average approximately five seconds after throttle chop. As forward speeds increased toward V_{cr} these rates of descent decreased accordingly. This is shown in Table II which lists runs obtained in the vicinity of h_{cr} and V_{cr}. With few exceptions, whether entry was from high hover or in the "knee" area, the incremental vertical accelerations following simulated power failure varied between +.5 and +.8 g's.

It is interesting to note that all high hover and near high hover points developed load factors at ground contact of less than two. This is compared to all the data points taken in the vicinity of the "knee" (V_{cr}, h_{cr}) wherein all the load factors at ground contact were well over two. This peculiarity would lead one to suspect that the high hover points might be conservative. This consistent distribution of landing load factors is explainable, however, in that in all the high hover and near high hover runs, the pilot was able to execute a full cyclic flare, thus building up sufficient rotor speed so that collective pitch application cushioned the impact. For those runs in the vicinity of and below the "knee", it was not possible to develop a full cyclic flare with its consequent rotor speed build up, and the landing was made with the application of collective pitch utilizing available rotor speed only. With the low inertia rotor system of the test aircraft it was not possible to develop the required energy for low contact velocities without the vital contribution of cyclic flare.

One other factor entered into the picture with respect to the high hover and near high hover data. Directional control difficulties occurred immediately after throttle chop. These were the result of rapid rotor speed decay and thus rapid tail rotor speed decay, both of which are attributable to the low rotor inertia. The problem was most pronounced at the higher altitudes and weight where power required to hover was highest. This is discussed under "Pilot's Comments" in Appendix 2.

Figures 9 through 11 show a comparison of time history data for high hover, low hover, and the critical speed area for sea level versus high altitude. The figures show that the control inputs and aircraft attitude are quite similar and in some cases almost identical over the range of altitudes and weights. The comparison of the high hover and V_{cr}, h_{cr} dat includes 1600 lb. data at 5000 feet in order to show the effects of weigh versus altitude. The 1600 lb. data at 5000 feet is practically identical to the 1450 lb. data at 7000 feet altitude.

Discussion of One-Second Delay

It was anticipated prior to the initiation of testing that, because of the low rotor inertia, a step might exist at the "knee" of the H-V diagram in transitioning from a no-delay maneuver to a one-second-delay maneuver. It was decided, therefore, to conduct the project throughout with no-delay in collective pitch reduction and do some one-second delay maneuvers to ascertain what the effect would be. The data obtained utilizing a one-second delay in collective pitch reduction following throttle cut did show a marked step in the curve. This increase in entry speed for a given height held throughout the upper boundary such that the height at high hover (h_{min}) was also markedly increased. In developing the H-V diagrams and thus the cross plots and final relationships, it was desirable to treat the delay and no-delay data of the upper boundary as separate H-V diagrams. Examination of the time histories of equal height delay and no-delay data revealed no specific characteristic differences. The rotor speed after a one-second delay fell off more sharply from throttle cut than the no-delay which evidenced a more gradual decay from throttle cut. The pilot apparently accomodated the more rapid rotor speed decay through an increase in entry speed or in the case of h_{min} through an increase in height. The relationship between V_{cr} and h_{min} appears to be consistent independent of the time of collective pitch reduction.

Effects of Weight and Altitude

As previously discussed, H-V diagrams were individually drawn throug each set of test points and then cross plots constructed of speed versus weight and altitude from which final H-V diagrams were drawn. The controlling points of the H-V diagrams such as V_{cr}, h_{min} and h_{max} were then cross plotted in a manner to define the H-V diagram relationships.

These cross plots are shown in Figs. 12 through 15. The high hover height, h_{min}, is shown to vary linearly with the square of the critical speed independent of weight, altitude and the time delay in collective pitch reduction as shown in Fig. 16. A set of H-V diagrams resulting from these tests can be partially defined in terms of the critical governing points on the H-V diagram which can be obtained from a set of linear equations. These equations are basically identical to those obtained in Reference 1. The differences between these equations and

those of the previous tests are in the constants which define the slopes of these linear expressions. The height, h_{cr}, must also be known in order to properly locate the point V_{cr}, h_{cr}. In the previous tests, h_{cr} was reported as essentially constant at approximately 95 feet. The current tests clearly indicate that h_{cr} increases with weight and altitude as shown on Fig. 6 by the dotted lines. Throughout the ranges of weights and altitudes tested this height varied from about eighty feet to approximately one hundred feet. Inasmuch as the expression shown below for V_{cr} holds true for speeds at heights above and below the height for V_{cr} for approximately forty to fifty feet as well, the shape of the family of curves is seen to be relatively constant in the area of the "knee". Therefore, selecting an average h_{cr} of 90 feet would not effect the construction of the H-V diagrams. No attempt mas made to establish an expression for h_{cr}.

The equations shown below can also be used to determine the reduction in weight required for a constant H-V diagram as the altitude is increased. This can be obtained by drawing a horizontal reference line through the intersection of the basic weight and sea level as shown on Fig. 13. This is identical to the procedure developed in Reference 1 except that since the constants of this data are greater, the percentage reduction of gross weight in lbs. per 1000 feet of altitude will also be greater.

Equations

1. $V_{cr} = V_{cr}(test) + C_1 \Delta W + C_2 \Delta H_D$

where V_{cr} = critical velocity at a given weight and density altitude

$V_{cr}(test)$ - critical velocity obtained through test

$$C_1 = \frac{dVcr}{dW}$$

$$C_2 = \frac{dV_{cr}}{dH_D}$$

2. $h_{max} = h_{max}(test) + C_3 \;\Delta W + C_4 \;\Delta H_D$

where h_{max} = low hover height at a weight and density altitude

$h_{max}(test)$ = low hover height obtained through testing

$$C_3 = \frac{dh_{max}}{dW}$$

$$C_4 = \frac{dh_{max}}{dH_D}$$

3. $h_{min}\ K + C_5\ V_{cr}^2$

where K = a constant (the h_{min} intercept)

$$C_5 = \frac{dh_{min}}{dV_{cr}^2}$$

The constants of these empirical equations are applicable only to the test helicopter as were the constants of Reference 1. It is interesting to note, however, that both tests resulted in a set of linear expressions in which only the constants were different. Further, a brief comparative examination of the data of both tests indicates other correlating factors. It appears possible, therefore, that a set of equations can be obtained by the application of a nondimensional analysis of the basic parameters and test results of the helicopter used in this project and in similar projects of this program, which would be applicable to all single engine, single rotor helicopters. Such an analysis might determine whether H-V diagrams can be predicted or developed over a range of weights and altitudes from single weight and altitude test data. No attempt has been made to do this in this report.

CONCLUSIONS

Based upon the tests of this small single rotor helicopter and an analysis of the test results it can be concluded that:

1. The H-V diagrams for this helicopter at different weights and altitudes form a family of curves for the altitudes and weights tested which are defined by a set of equations involving key points on the H-V diagram such as V_{cr}, h_{min} and h_{max}. These equations show that:

   a. V_{cr} is a linear function of weight or altitude.

   b. h_{max} is a linear function of weight or altitude.

   c. h_{min} is a linear function of V_{cr}^2.

2. The height (h_{cr}) for critical velocity (V_{cr}) increases over the range of weights and altitudes tested varying between eighty to one hundred feet. Since the shape of the H-V curves are relatively constant in the area of the "knee", a constant average height of ninety feet for h_{cr} can be assumed without destroying the family relationships of these curves.

REFERENCES

1. W. J. Hanley and G. DeVore, An Evaluation of the Effects of Altitude on the Height Velocity Diagram of a Single Engine Helicopter, Technical Report ADS-1, February, 1964.

BIBLIOGRAPHY

1. W. D. Jepson, Some Considerations of the Landing and Take-off Characteristics of Twin Engine Helicopters, Journal of AHS, Part I, October, 1962.

2. M. J. Rich, An Energy Absorption Safety Alighting Gear for Helicopter and VTOL Aircraft, IAS Paper No. 62-16, January, 1962.

3. E. F. Katzenberger and M. J. Rich, An Investigation of Helicopter Descent and Landing Characteristics Following Power Failure, Journal of Aero Sciences, April, 1956.

4. Alexander Klemin, Principles of Rotary Wing Aircraft, Reprint Aero Digest, 1945.

5. A. Gessow and G. C. Meyers, Aerodynamics of the Helicopter, The MacMillar Co., C 1952.

6. D. Dommasch, Elements of Propeller and Helicopter Aerodynamics, Pitman Publishing Company, C 1953.

TABLE I

SUMMARY OF HIGH HOVER (h_{min}) AND NEAR HIGH HOVER DATA

FLT NO.	RUN NO.	G.W. (1) (lbs)	H_D (2) (feet)	t_1 (3) (sec)	A_1 (4) (Δg)	V_D (5) (ft/sec)	t_2 (6) (sec)	h_{TC} (7) (feet)	t_3 (8) (sec)	Ω_1 (9) (rpm)	t_4 (10) (sec)	V_{TC} (11) (kts)	V_{TD} (12) (kts)	Ω_2 (13) (rpm)	A_2 (14) (g's)	Ω_3 (15) (rpm)	Ω_4 (16) (rpm)	Ω_5 (17) (rpm)
46	13*	1465	-300	.12	.87	-42.5	5.28	263	4.00	451	2.10	0.2	11.4	300	1.40	480	435	469
46	14*	1450	-350	.10	.74	-43.0	5.07	270	4.80	444	2.10	3.9	9.4	311	1.50	472	409	469
46	15*	1447	-350	.12	.87	-41.7	5.30	255	5.33	448	1.93	4.9	10.8	311	1.62	480	409	469
46	16*	1465	-400	.12	.70	-43.8	5.11	248	5.15	444	1.75	5.4	13.4	300	2.05	470	429	462
50	10	1461	-450	.05	.78	-44.0	4.70	230	5.06	432	2.66	10.5	16.9	295	1.39	480	429	462
50	16*	1449	-350	.86	.96	-44.3	6.13	310	4.14	468	1.94	3.0	17.7	395	1.41	478	395	480
50	19*	1451	-850	.75	.71	-45.6	5.68	310	5.07	445	1.57	3.4	16.6	330	1.55	465	400	462
50	9	1453	- 50	.80	.59	-44.0	5.20	253	6.30	425	2.40	11.1	17.3	308	1.55	469	400	455
50	10	1450	- 50	1.10	.59	-43.6	5.50	245	5.11	429	2.51	11.4	19.3	405	1.78	470	400	455
56	10	1605	-350	.11	.65	-45.3	4.94	243	5.46	444	1.86	5.8	18.7	293	2.11	465	432	462
56	11	1602	-250	.08	.73	-45.3	4.82	250	5.01	455	2.11	10.6	18.4	313	1.41	469	425	469
56	13*	1504	- 50	.12	.77	-46.2	4.62	290	3.97	465	1.47	4.9	19.4	360	1.81	465	425	480
61	3	1595	-1000	1.0	.67	-41.6	5.50	262	4.46	440	1.46	16.5	22.7	330	1.31	478	400	465
61	4	1601	-950	.91	.54	[illegible]	5.73	262	5.08	435	2.18	18.6	20.5	316	1.62	480	400	462
61	5	1598	-900	1.0	.54	43.9	5.58	252	4.46	442	2.16	17.3	21.6	293	1.36	490	400	462
19	14*	1447	5000	.19	.72	-57.0	4.23	307	5.89	429	1.99	-0.4	17.4	311	1.87	478	414	480
26	10	1448	4500	1.08	.46	-56.4	5.10	290	5.47	438	1.87	20.7	13.3	316	2.10	469	395	462
28	10*	1455	5400	.19	.73	-56.0	4.05	346	4.28	445	1.38	6.4	19.1	365	1.83	475	414	480
28	11*	1452	5350	.18	.79	-56.3	5.13	383	4.64	444	1.64	5.7	18.1	315	1.56	480	413	462
28	13*	1447	5400	.66				418				4.9	17.5		1.52			
28	14*	1453	5500	UNK				415				3.4	11.5		1.41			
30	8*	1455	5700	.13	.80	-55.2	4.54	325	5.09	442	1.79	2.0	22.1	345	1.60	475	414	485
30	4	1447	5800	.15	.43	-55.0	4.36	278	5.50	435	1.80	18.0	10.3	310	2.06	475	411	465
41	5	1450	4150	.15	.76	-44.6	4.78	252	3.40	435	1.80	13.9	12.1	324	1.75	480	420	469
41	6	1447	4050	.10	.57	-42.5	5.30	251	5.62	420	2.12	11.5	14.1	288	1.78	469	420	448
41	11*	1443	4400	.11	.57	-48.3	5.77	321	4.56	480	2.06	2.5	14.8	360	1.32	490	436	490
88	17	1586	5300	.06				390				8.3	14.6		N/A			
88	11	1580	5800	.15	.65	-55.3	3.95	338	3.37	500	1.87	20.6	12.5	385	1.78	480	409	508
88	13	1601	5300	.07	.68	-55.4	4.92	390	3.41	505	2.11	16.5	11.4	342	2.30	500	440	505
88	15*	1600	5050	.12	.93	-55.3	6.01	445	3.08	508	1.64	-2.0	13.3	365	1.96	469	380	508
85	13	1608	5100	1.00	.66	-57.4	5.11	396	3.79	500	2.39	23.5	12.3	384	1.87	465	377	500
85	14	1602	5000	1.12	.40	-56.7	5.00	382	3.10	480	1.90	15.8	13.8	316	1.69	480	387	490
85	5	1598	5000	.77	.53	-56.0	4.53	338	3.61	505	2.21	29.4	11.0	330	1.78	478	400	508
88	11*	1608	5100	.27	.82	-54.7	4.70	459	3.71	510	1.81	0.7	14.8	366	1.63	465	411	513
88	13*	1603	5085	.98	.83	-54.3	4.65	484	3.56	500	1.86	-0.4	11.4	366	1.53	469	380	528
85	14*	1600	5250	.79	.71	-53.4	4.40	478	3.18	522	1.48	0.6	11.3	355	1.54	465	380	528
89	15*	1605	5875	.18	.86	-54.3	3.72	432	3.32	522	2.12	4.6	14.6	323	1.73	465	414	528
36	7	1449	6550	.13	.61	-46.0	4.05	389	3.43	500	2.13	20.5	UNK	355	1.43	480	408	500
36	16*	1448	7800	.19	.70	-47.0	5.06	430	4.21	500	2.11	0.27	9.6	310	1.51	465	408	513
36	18*	1450	7400	.82	1.07	-47.2	5.70	51.	2.89	510	1.89	2.5	11.1	360	1.54	474	375	528
37	5	1452	6600	.19	.59	-47.0	5.79	354	3.76	490	1.96	16.8	15.0	365	1.55	475	415	495
37	20	1451	7250	.21	.67	-47.0	7.55	375	3.03	520	2.33	7.0	13.9	345	1.48	470	412	520
37	23	1451	7300	1.10	.50	-47.0	7.40	312	3.52	492	2.12	29.4	15.1	350	1.54	476	392	490

COLUMN LEGEND

(1) G. W. - Test gross weight of the helicopter
(2) H_D - Density altitude of test
(3) t_1 - Time delay after throttle cut before application of collective pitch
(4) A_1 - Maximum change of acceleration from 1g encountered during descent
(5) V_D - Maximum rate of vertical descent encountered during maneuver
(6) t_2 - Elapsed time between throttle cut and attainment of maximum rate of descent
(7) h_{TC} - Height over the ground at throttle cut
(8) t_3 - Elapsed time between start of "up collective" and touchdown
(9) Ω_1 - Rotor speed at start of "up collective"

(10) t_4 - Elapsed time between maximum "nose up" attitude and touchdown
(11) V_{TC} - Calibrated airspeed at throttle cut
(12) V_{TD} - Calibrated airspeed at touchdown
(13) Ω_2 - Rotor speed at touchdown
(14) A_2 - Peak acceleration at touchdown
(15) Ω_3 - Rotor speed at throttle cut
(16) Ω_4 - Minimum rotor speed obtained prior to flare.
(17) Ω_5 - Maximum rotor speed obtained during flare to landing.

* High hover points

TABLE II

SUMMARY OF TYPICAL DATA-AREA OF CRITICAL SPEED (V_{cr}) AND CRITICAL HEIGHT (h_{cr})

FLT NO.	RUN NO.	G.W. (1) (lbs)	H_D (2) (Feet)	t_1 (3) (sec)	A_1 (4) (Δg)	V_D (5) (ft/sec)	t_2 (6) (Sec)	h_{TC} (7) (Feet)	t_3 (8) (Sec)	Ω_1 (9) (RPM)	t_4 (10) (sec)	V_{TC} (11) (MPH)	V_{TD} (12) (MPH)	Ω_2 (13) (RPM)	A_2 (14) (g's)	Ω_3 (15) (RPM)	Ω_4 (16) (RPM)	Ω_5 (17) (RPM)
46	10	1448	-450	.14	.75	-30.0	2.90	100	4.02	444	1.62	23.6	13.4	300	2.86	480		
46	19	1446	-350	.13	.67	-23.0	2.43	72	4.40	444	1.50	22.3	13.7	300	1.78	480		
48	11	1443	-400	.10	.62	-17.0	2.40	48	3.10	455	1.20	22.4	UNK	293	2.03	480		
50	3	1448	-700	.16	.52	-17.0	2.17	49	3.05	455	1.45	26.3	19.1	303	1.93	488		
50	6	1447	-650	.17	.56	-24.0	2.74	81	3.84	435	1.24	22.3	18.4	311	2.63	480		
58	2	1453	+400	.11	.73	-31.6	3.66	146	4.60	432	1.40	20.0	15.0	340	2.53	500	431	448
58	3	1450	+500	.14	.94	-32.7	3.60	144	3.54	429	1.04	16.4	18.7	325	2.32	469		
58	4	1445	+500	.08	.66	-15.5	2.14	55	3.64	462	1.34	25.6	17.6	310	2.26	485		
58	5	1451	+400	.80	.97	-17.5	2.18	51	3.06	462	1.46	21.9	20.8	316	2.32	485		
59	3	1447	- 50	.90	.66	-30.3	3.59	104	4.71	405	1.71	30.5	15.5	279	2.02	469	[illegible]	405
59	4	1454	- 50	.96	.74	-29.3	3.80	98	4.19	400	1.69	29.8	22.0	286	2.50	469	398	410
49	13	1604	-250	.14	.52	-17.9	2.24	54	3.23	435	1.23	26.3	UNK	303	2.81	462		
53	8	1604	-300	.18	.65	-31.3	2.93	100	3.72	429	1.42	25.6	17.3	308	2.72	469		
56	4	1600	-550	.11	.56	-25.1	2.39	72	3.61	458	1.01	26.3	23.6	297	2.47	480		
56	7	1601	-500	.13	.82	-34.5	3.83	153	4.18	435	1.28	22.5	18.4	350	2.80	480	435	[illegible]
56	17	1596	- 50	.97	.61	-38.8	4.18	142	4.28	400	1.28	32.3	22.9	305	2.70	480	[illegible]	465
57	1	1607	+100	1.02	.62	-27.2	3.76	97	3.81	423	1.61	37.3	19.6	324	3.25	469	408	[illegible]
19	2	1451	4800	.47	.58	-25.5	2.67	72	4.35	420	1.65	33.1	16.4	320	3.45	482		
19	5	1438	4850	.19	.48	-21.3	1.99	49	3.41	430	2.01	38.2	22.9	309	2.09	465		
26	15	1451	5650	.87	.44	-30.5	3.50	59	3.46	429	1.96	43.3	17.9	353	2.04	480	420	451
28	2	1451	5000	.26	.58	-34.0	2.56	94	4.16	432	1.66	35.5	28.6	305	2.45	478		
28	5	1451	5250	.13	.46	-34.0	2.10	109	4.68	429	1.88	38.1	18.6	319	2.29	480	429	444
39	2	1450	4800	.17	.50	-34.0	4.20	152	3.47	414	1.07	29.3	20.8	300	2.30	480	414	486
41	8	1450	4450	.07	.52	-35.7	3.35	143	4.90	444	1.80	24.9	23.3	300	2.61	495		
21	3	1599	4500	.06	.48	-37.0	3.55	150	5.32	429	1.52	42.0	17.1	335	2.20	480	429	462
22	3	1600	4300	.15	.63	-31.0	2.64	101	4.29	444	1.49	42.9	18.7	320	2.87	490		
22	4	1597	4300	.14	.56	-25.0	2.45	64	4.01	444	1.51	44.9	18.8	330	2.50	480		
25	10	1596	4900	1.18	.58	-32.3	3.00	98	4.01	400	1.71	51.9	20.2	316	2.60	462	400	429
29	3	1599	4700	.14	.50	-17.5	1.77	40	3.62	460	1.32	40.5	16.6	340	2.69	492		
36	14	1456	7100	.15	.52	-35.4	3.91	150	4.47	423	1.47	40.3	19.1	325	2.11	483	423	457
37	6	1448	6600	.16	.39	-30.0	3.45	106	4.17	429	1.47	43.3	19.4	335	2.43	480	429	448
37	9	1446	6650	.14	.48	-16.2	2.32	51	3.49	444	1.59	36.8	18.7	320	2.49	480		
37	14	1445	7000	.14	.49	-24.4	2.60	76	3.70	438	1.40	38.5	19.6	320	2.11	480	438	448
37	18	1445	7100	1.00	.55	-27.2	3.95	96	3.62	417	1.52	45.4	25.4	335	2.46	485	417	429

COLUMN LEGEND

(1) G. W. - Test gross weight of the helicopter
(2) H_D - Density Altitude of test
(3) t_1 - Time delay after throttle cut before application of collective pitch
(4) A_1 - Maximum change of acceleration from 1g encountered during descent
(5) V_D - Maximum rate of vertical descent encountered during maneuver
(6) t_2 - Elapsed time between throttle cut and attainment of maximum rate of descent
(7) h_{TC} - Height over the ground at throttle cut
(8) t_3 - Elapsed time between start of "up collective" and touchdown
(9) Ω_1 - Rotor speed at start of "up collective"
(10) t_4 - Elapsed time between maximum "nose up" attitude and touchdown
(11) V_{TC} - Calibrated airspeed at throttle cut
(12) V_{TD} - Calibrated airspeed at touchdown
(13) Ω_2 - Rotor speed at touchdown
(14) A_2 - Peak acceleration at touchdown
(15) Ω_3 - Rotor speed at throttle cut
(16) Ω_4 - Minimum rotor speed obtained prior to cyclic flare.
(17) Ω_5 - Maximum rotor speed obtained during flare prior to landing.

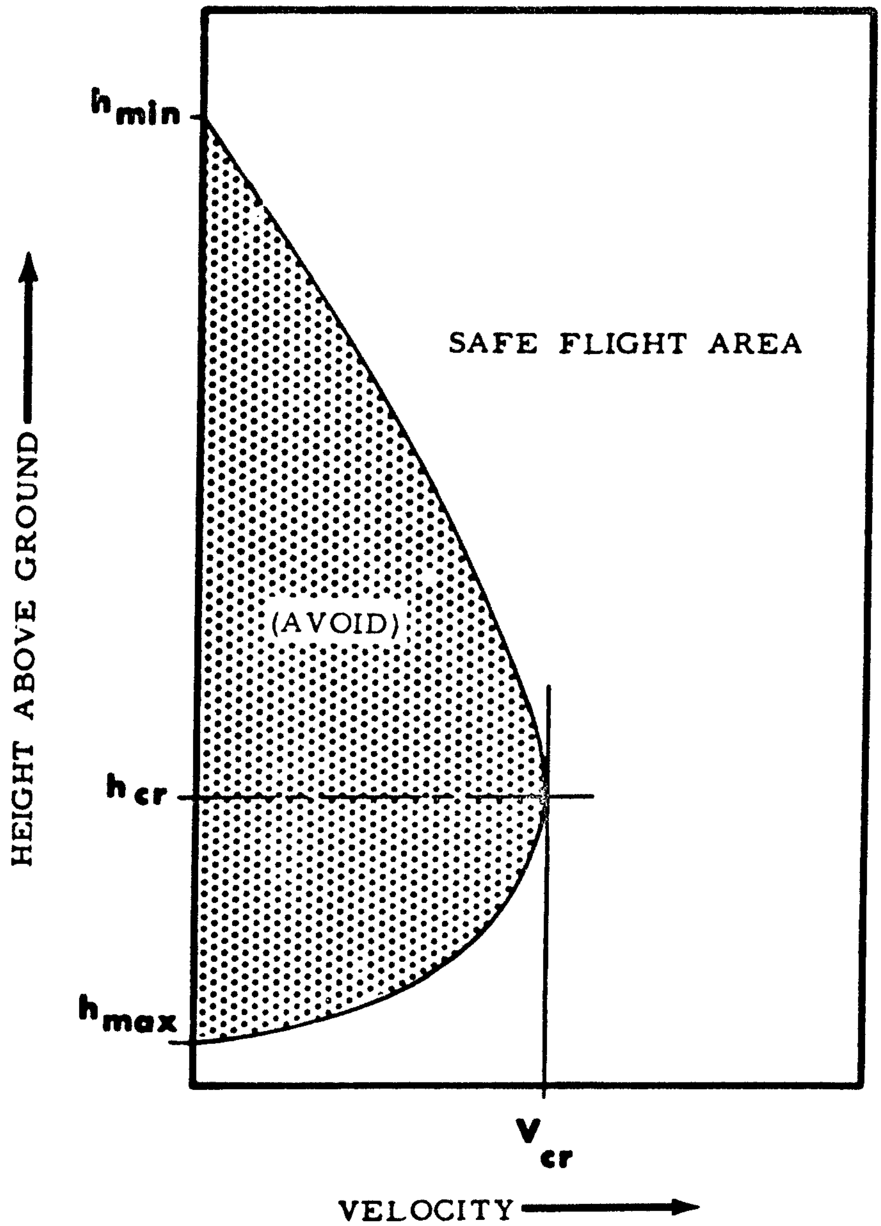


FIG. 1 TYPICAL HEIGHT-VELOCITY DIAGRAM

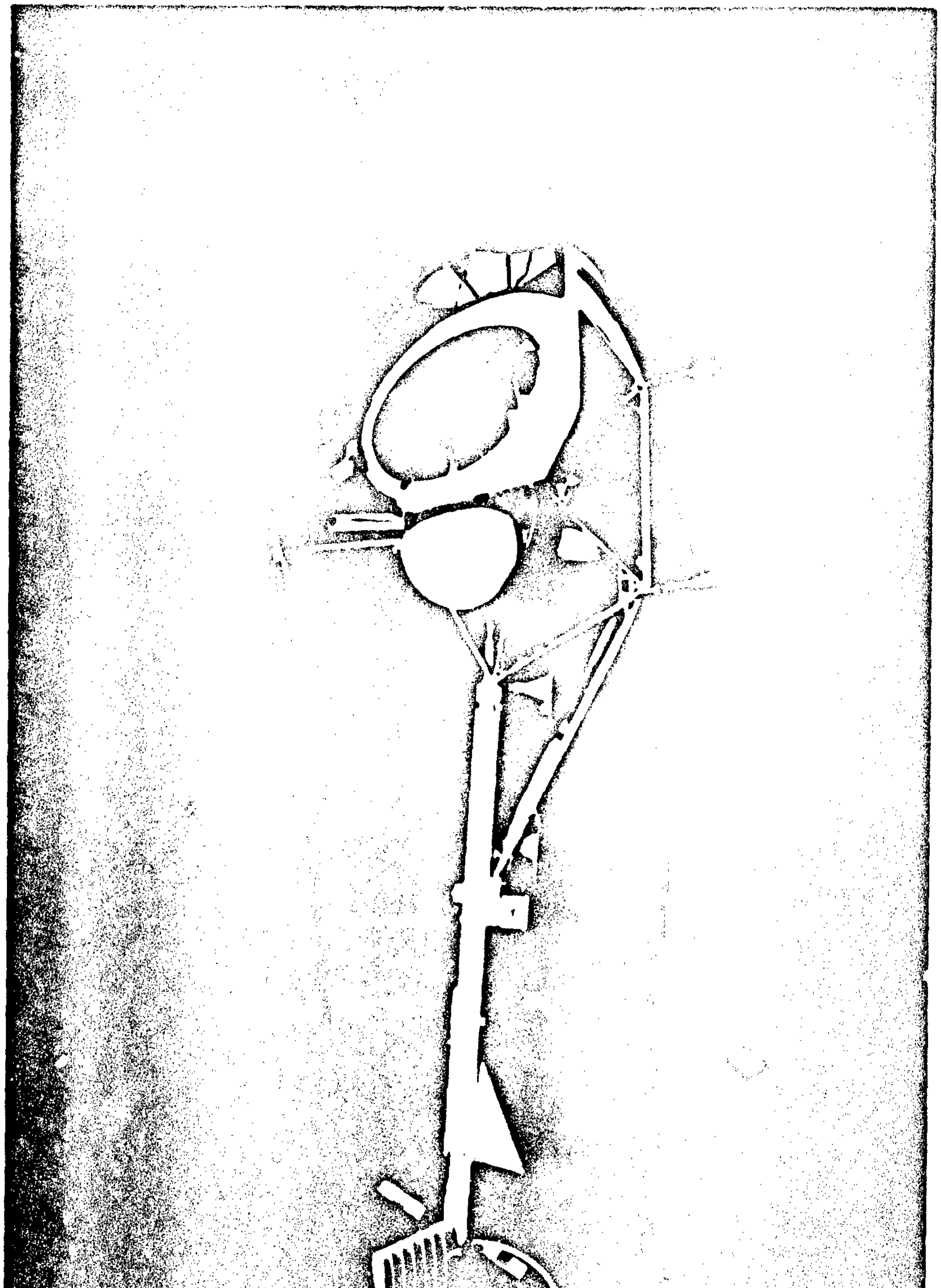


FIG. 2 TEST AIRCRAFT

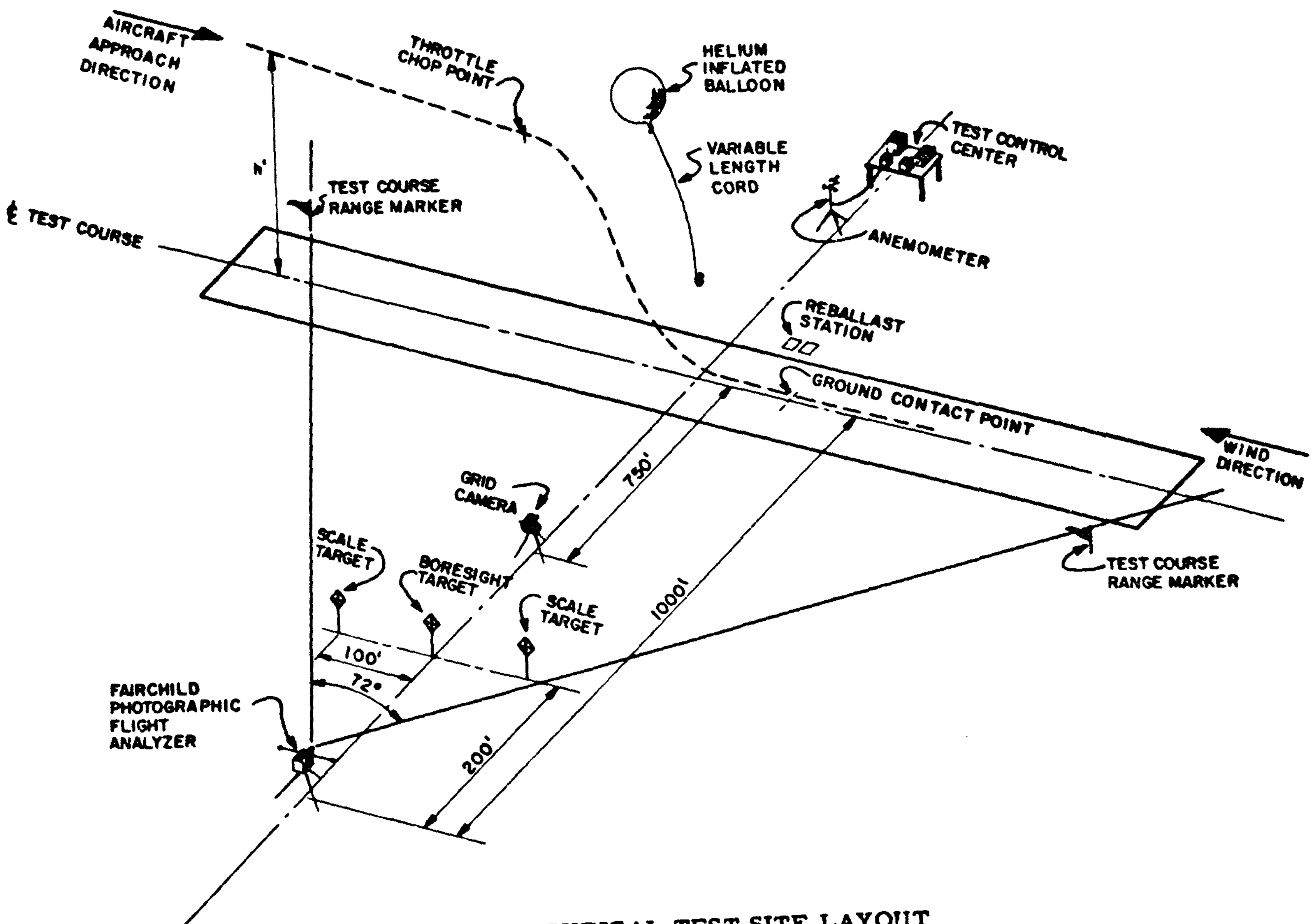


FIG. 3 TYPICAL TEST SITE LAYOUT

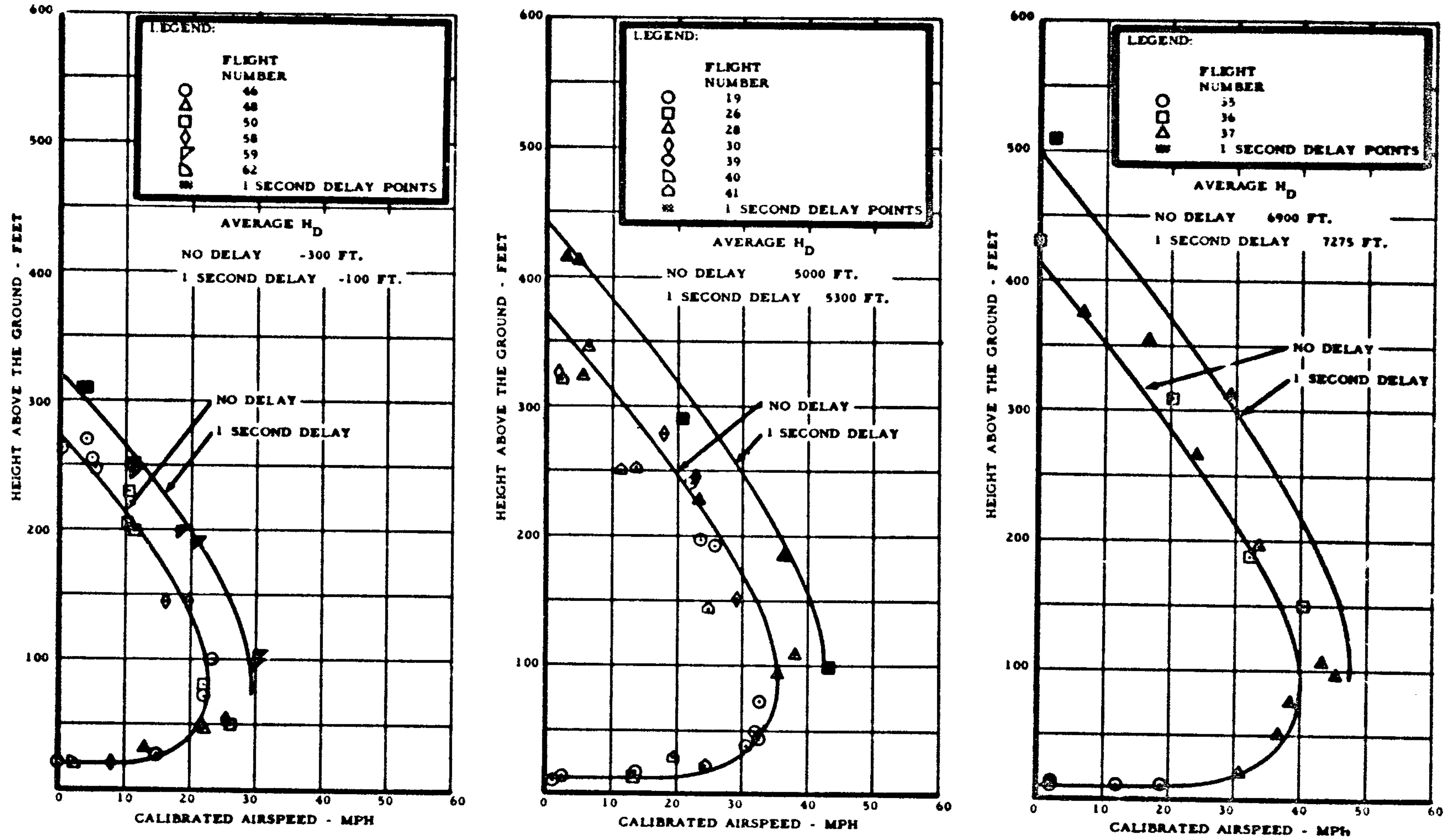


FIG. 4 HEIGHT-VELOCITY DIAGRAM - BASIC DATA
HELICOPTER GROSS WEIGHT 1450 POUNDS
THREE DENSITY ALTITUDES SHOWN

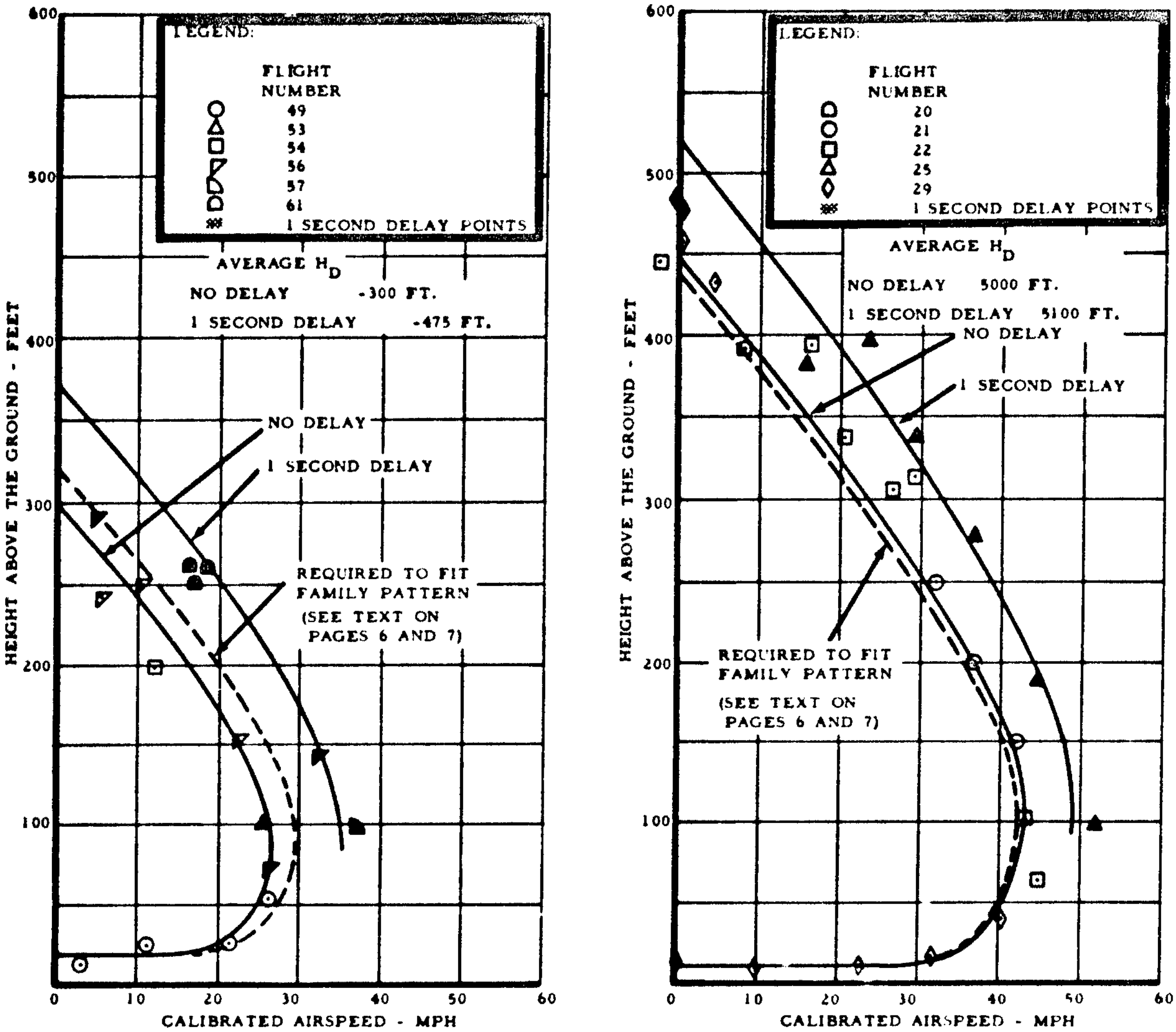


FIG. 5 HEIGHT-VELOCITY DIAGRAMS - BASIC DATA
HELICOPTER GROSS WEIGHT 1600 POUNDS
TWO DENSITY ALTITUDES SHOWN

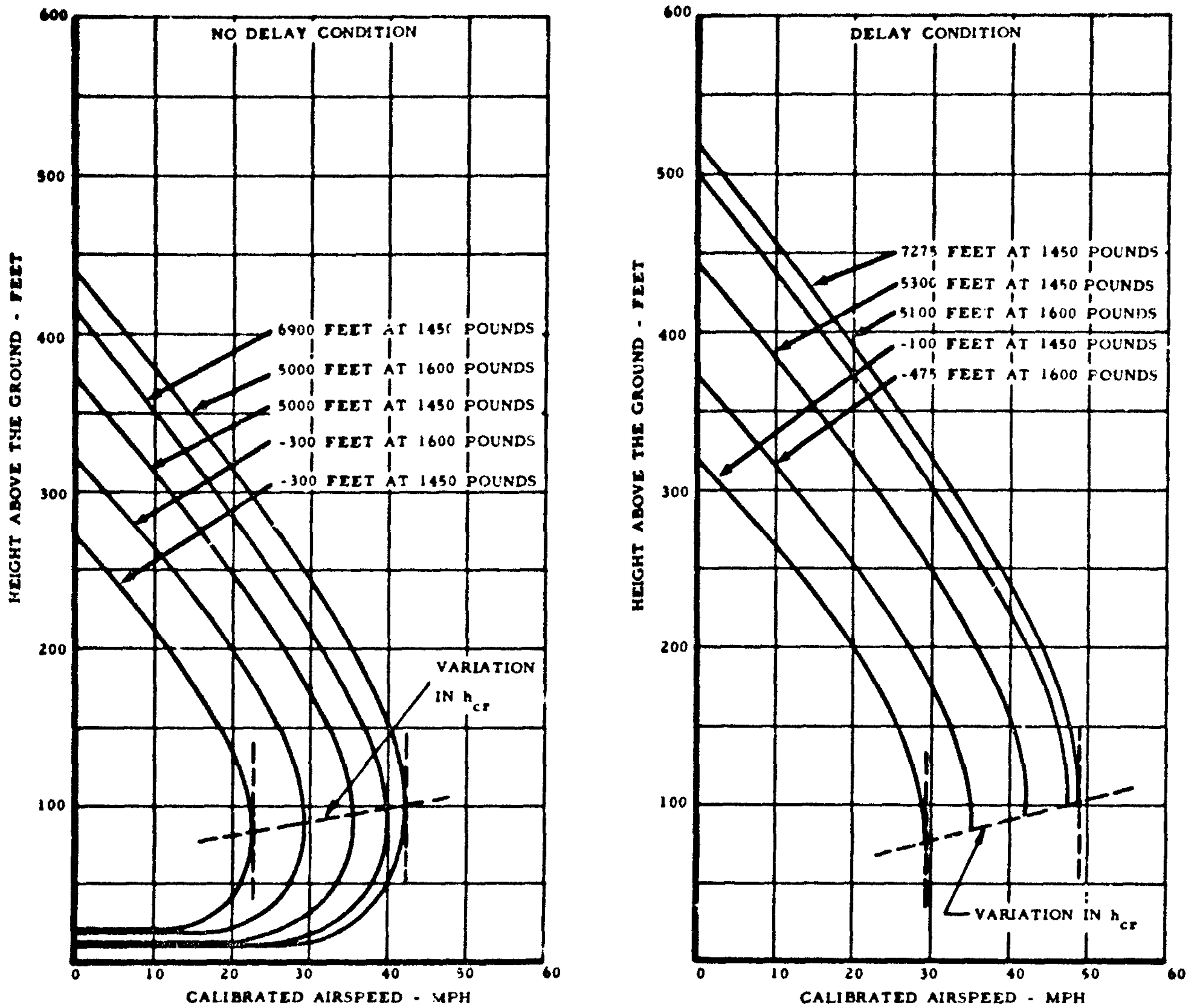


FIG. 6 HEIGHT-VELOCITY DIAGRAM VARIATION WITH DENSITY ALTITUDE AND GROSS WEIGHT-DELAY AND NO-DELAY CONDITIONS SHOWN

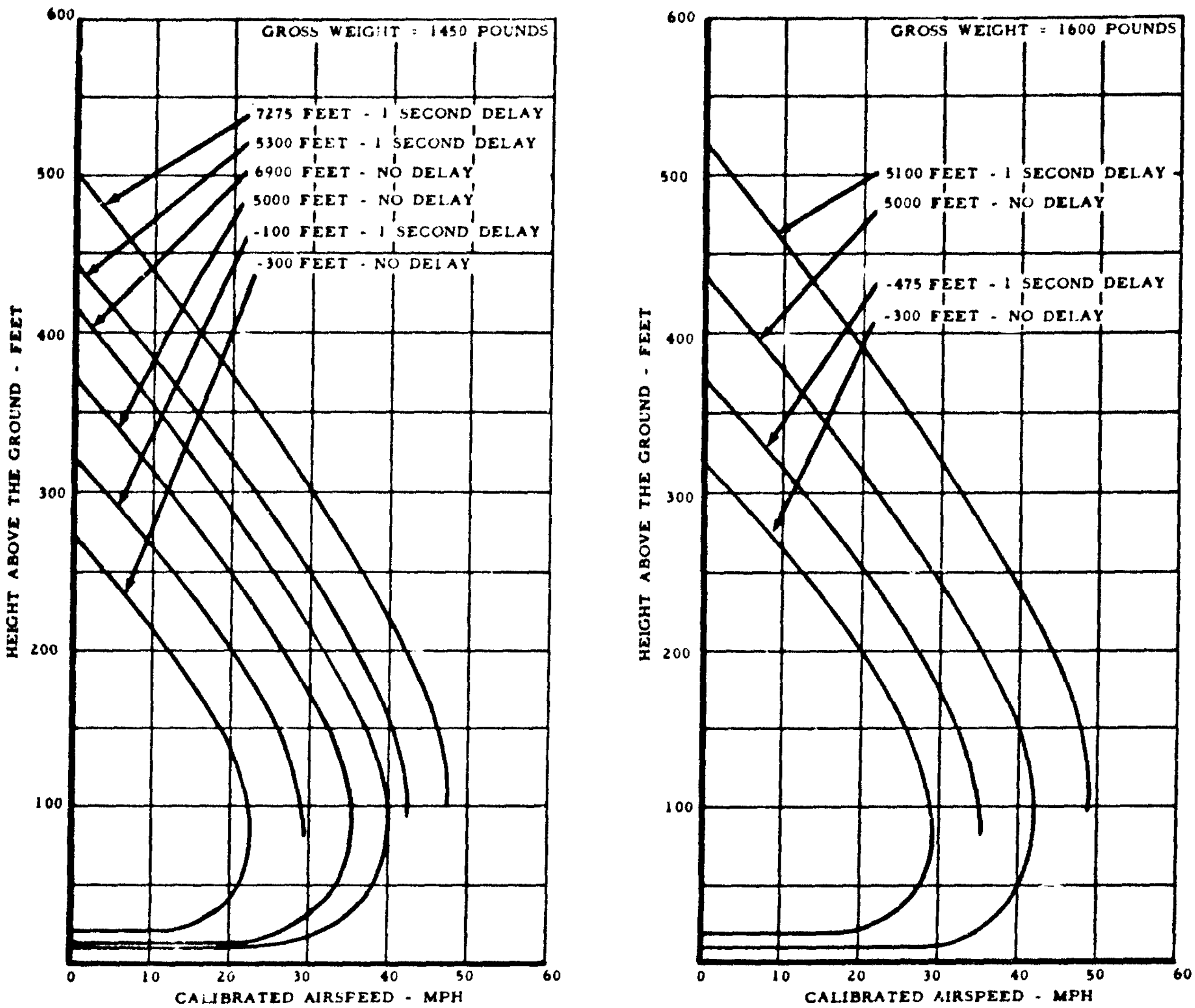


FIG. 7 HEIGHT-VELOCITY DIAGRAM VARIATION WITH DENSITY ALTITUDE AND GROSS WEIGHTS OF 1450 AND 1600 POUNDS SHOWN-DELAY AND NO-DELAY CONDITIONS

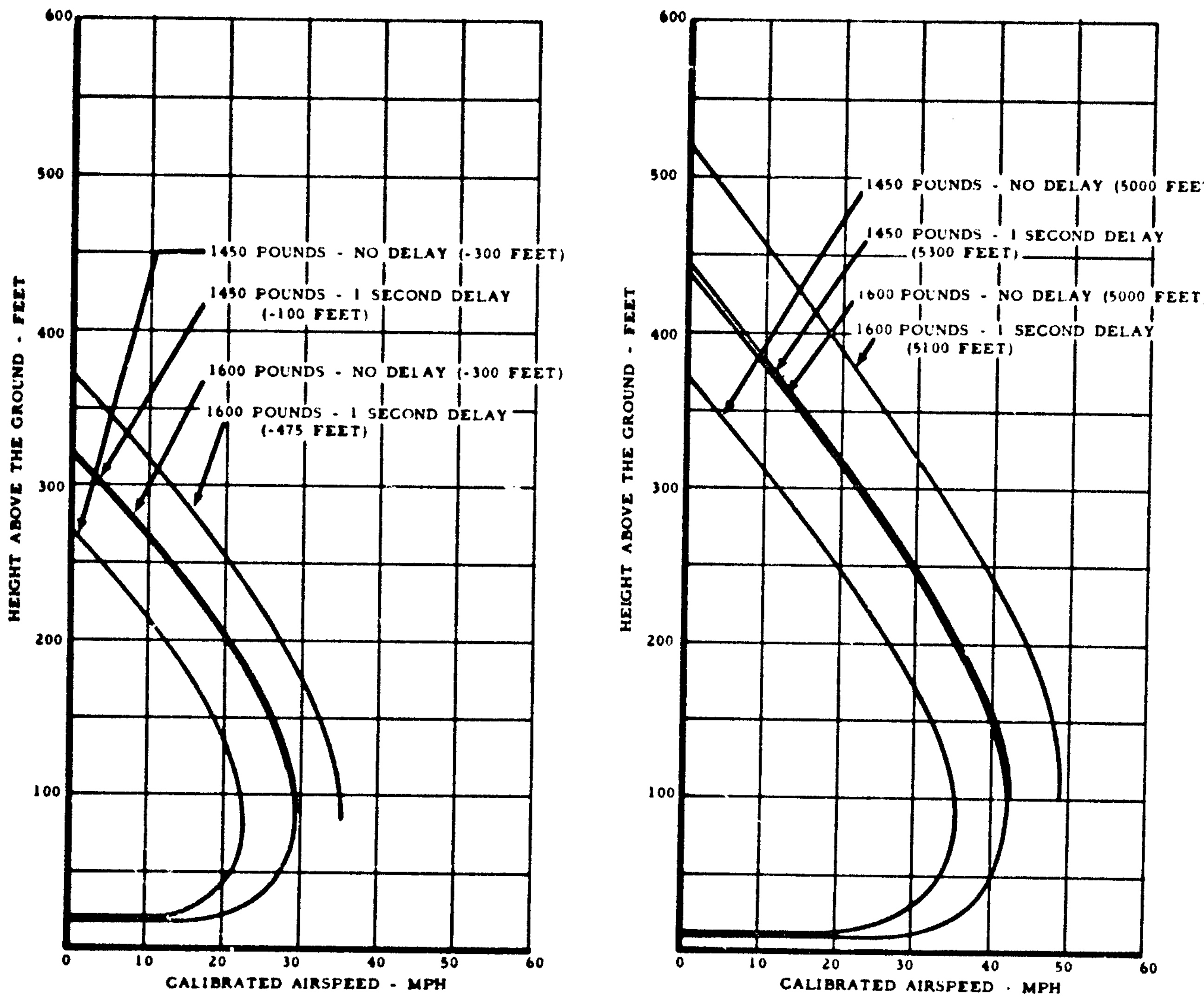


FIG. 8 HEIGHT-VELOCITY DIAGRAM VARIATION WITH GROSS WEIGHT AND DENSITY ALTITUDE SHOWN FOR DELAY AND NO-DELAY CONDITIONS

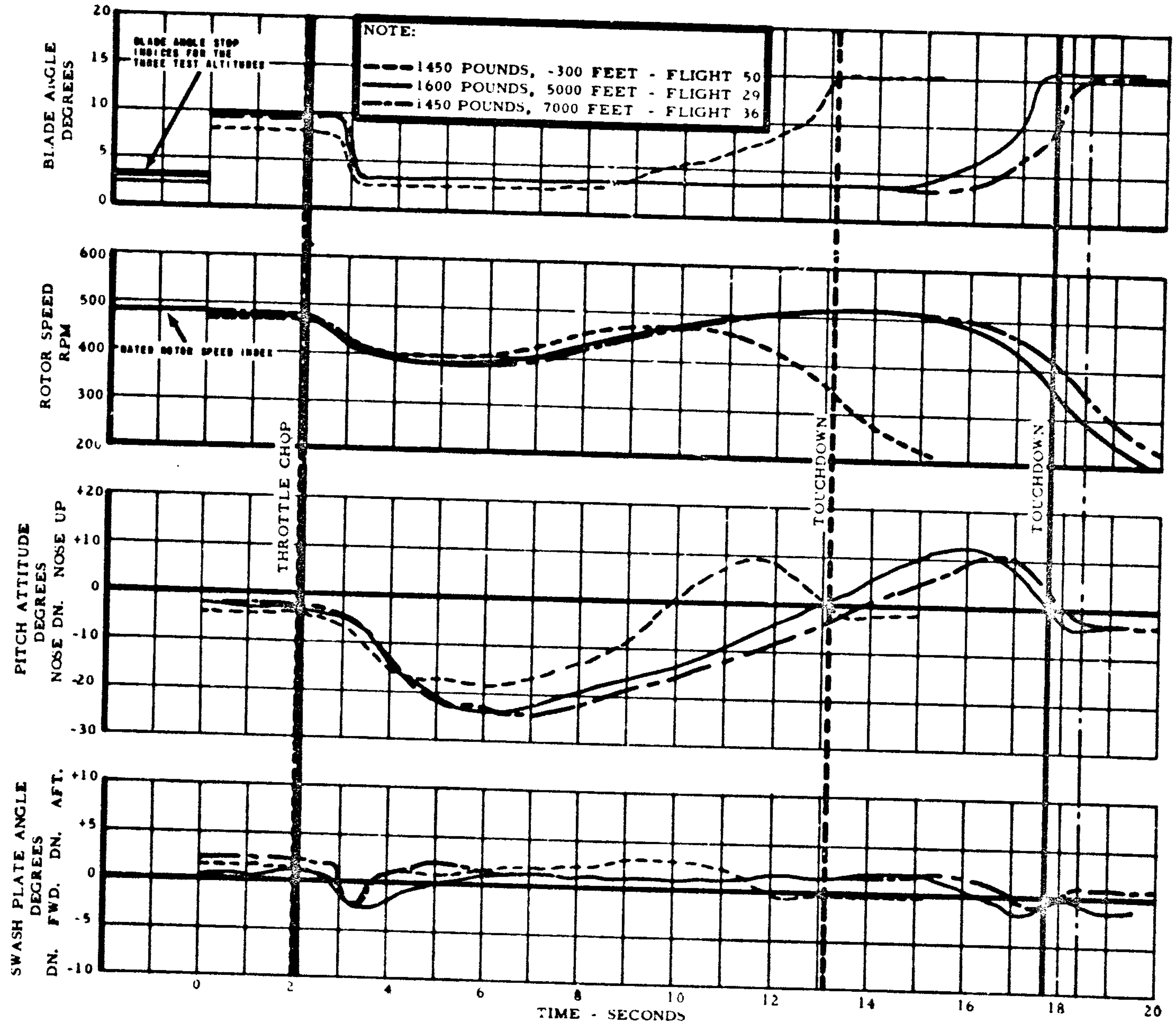


FIG. 9 COMPARISON OF TIME HISTORY DATA FOR HIGH HOVER POINTS

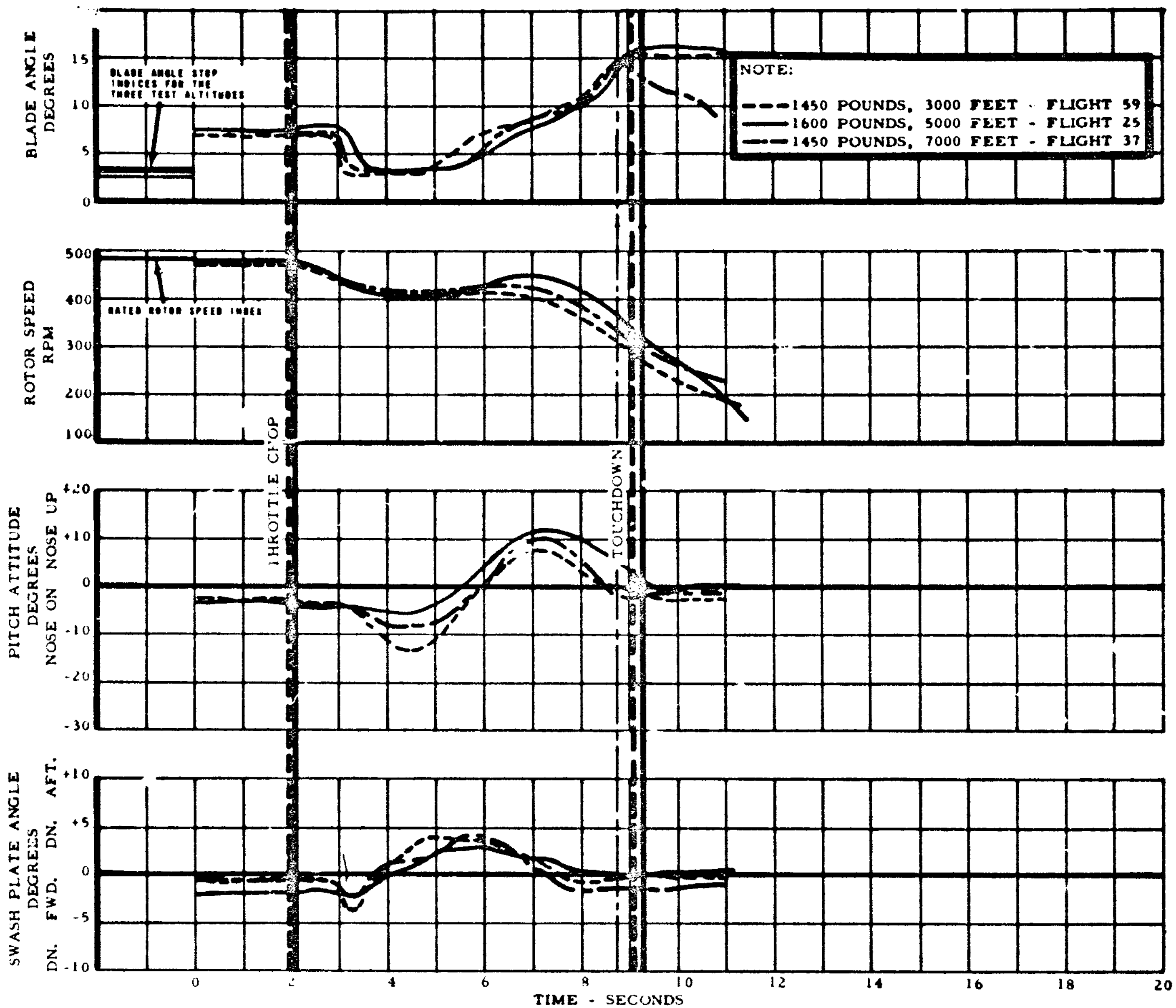


FIG. 10 COMPARISON OF TIME HISTORY DATA

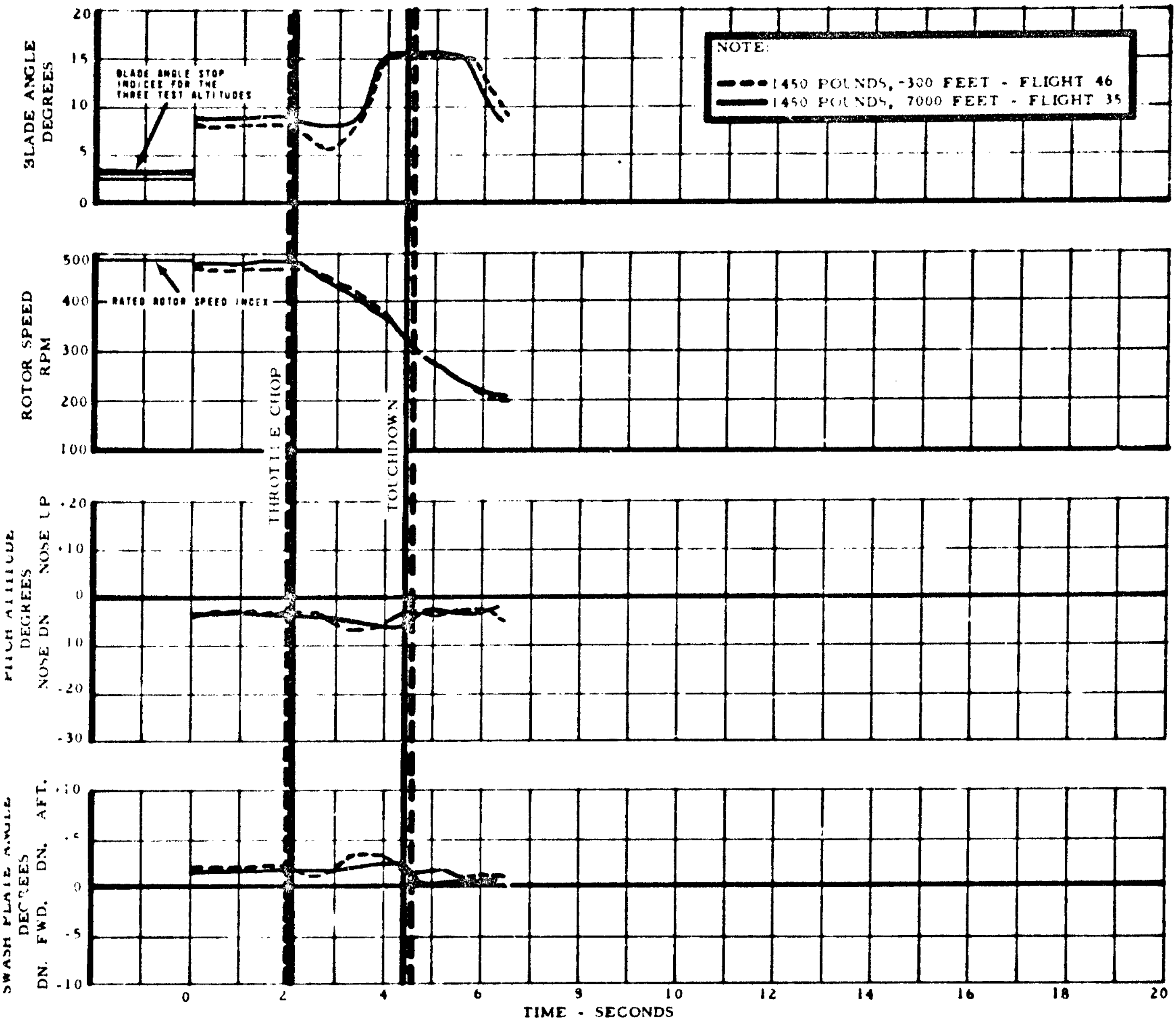


FIG. 11 COMPARISON OF TIME HISTORY DATA FOR LOW HOVER POINTS

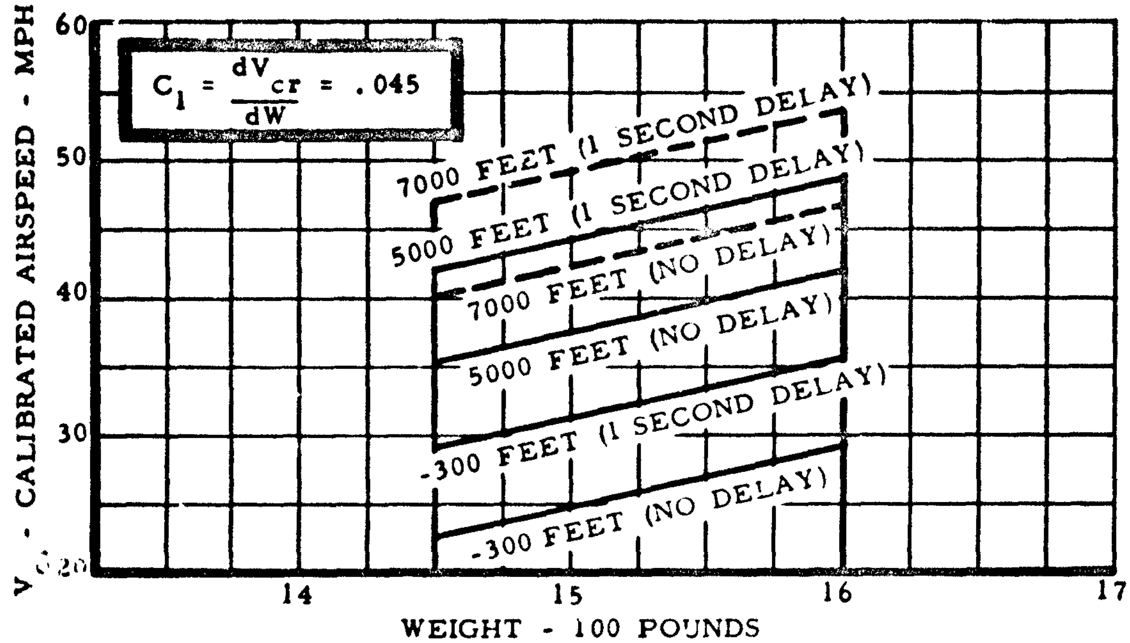


FIG. 12 CRITICAL VELOCITY (V_{cr}) VERSUS AIRCRAFT GROSS WEIGHT FOR THE RANGE OF TEST DENSITY ALTITUDES

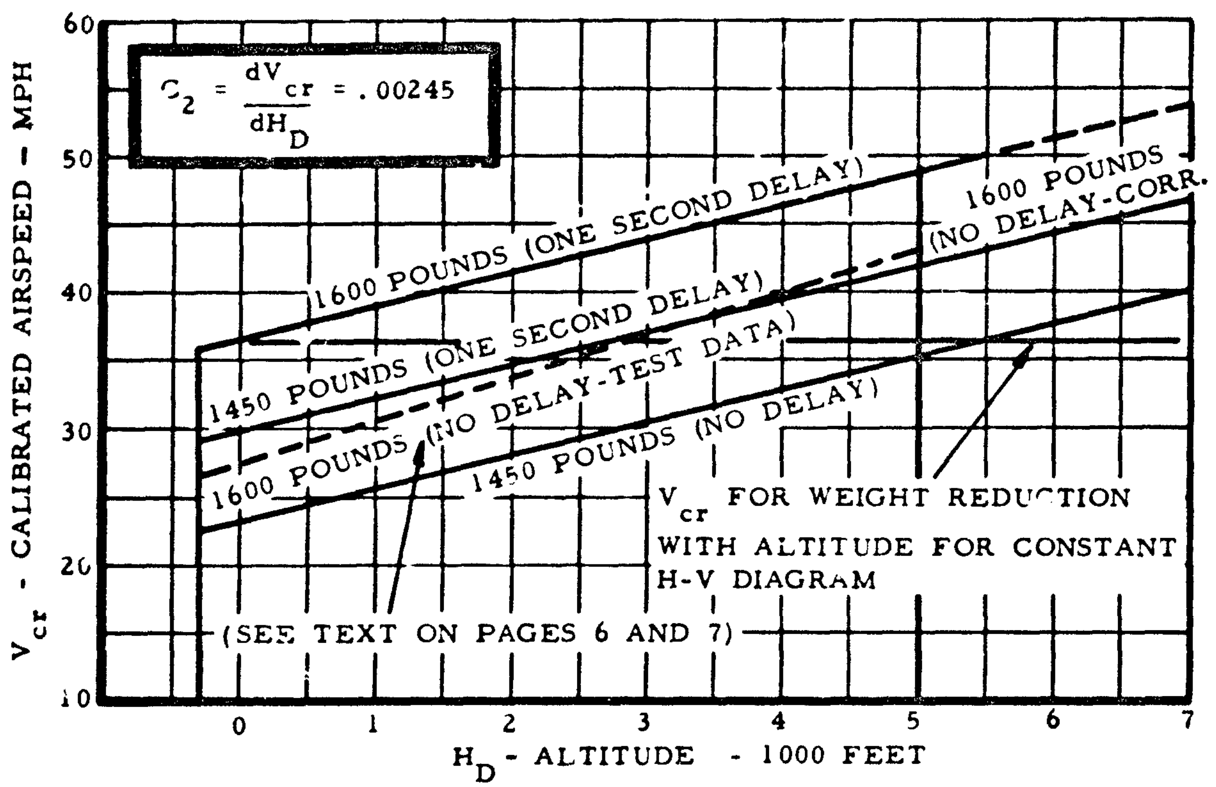


FIG. 13 CRITICAL VELOCITY (V_{cr}) VERSUS TEST ALTITUDE FOR THE RANGE OF TEST WEIGHTS

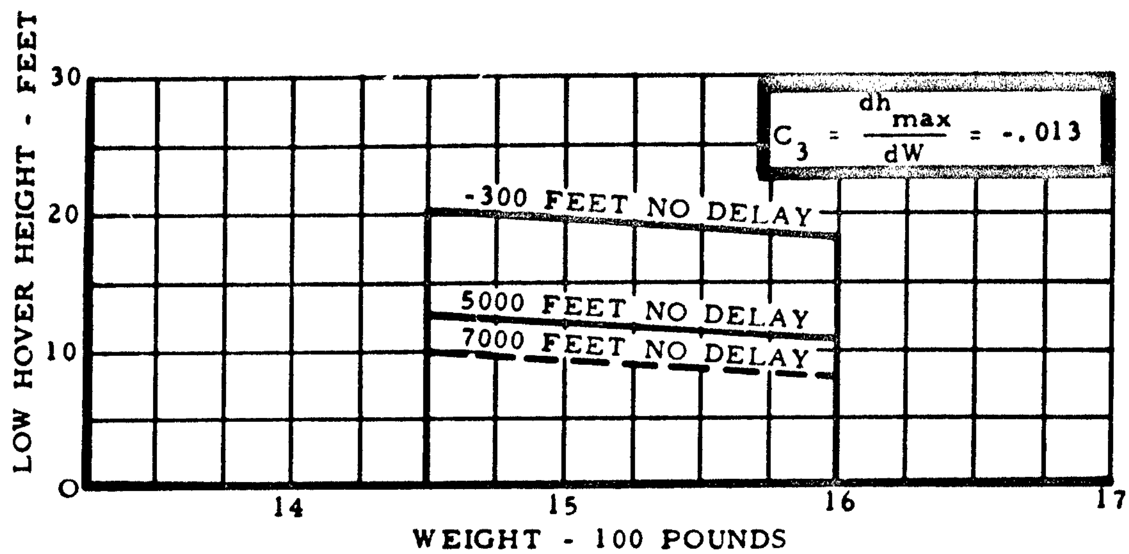


FIG. 14 LOW HOVER HEIGHT (h_{max}) VERSUS AIRCRAFT GROSS WEIGHT FOR THE RANGE OF TEST DENSITY ALTITUDES

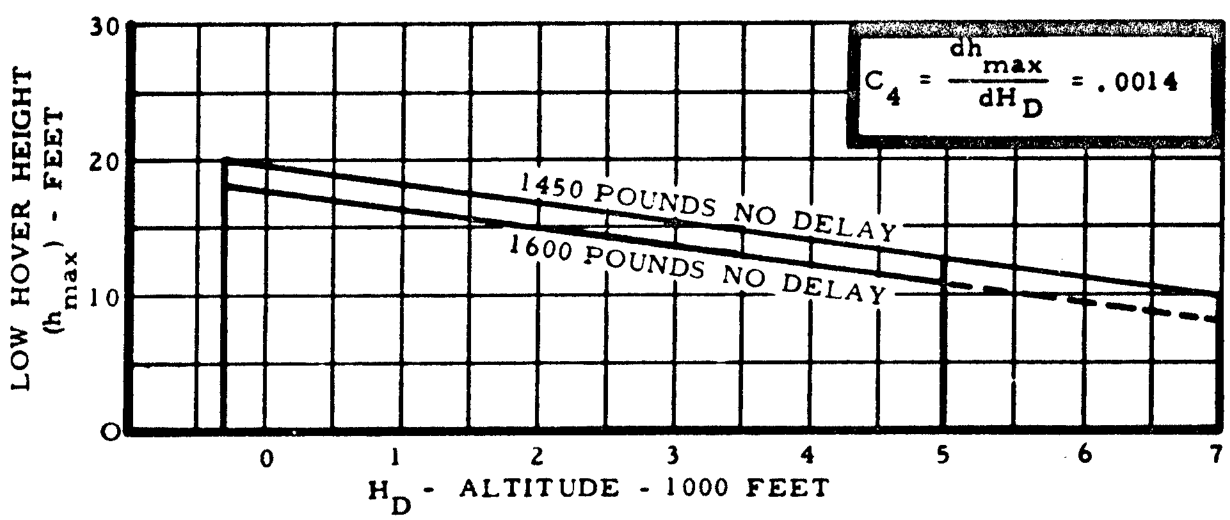


FIG. 15 LOW HOVER HEIGHT (h_{max}) VERSUS TEST ALTITUDE FOR THE RANGE OF TEST WEIGHTS

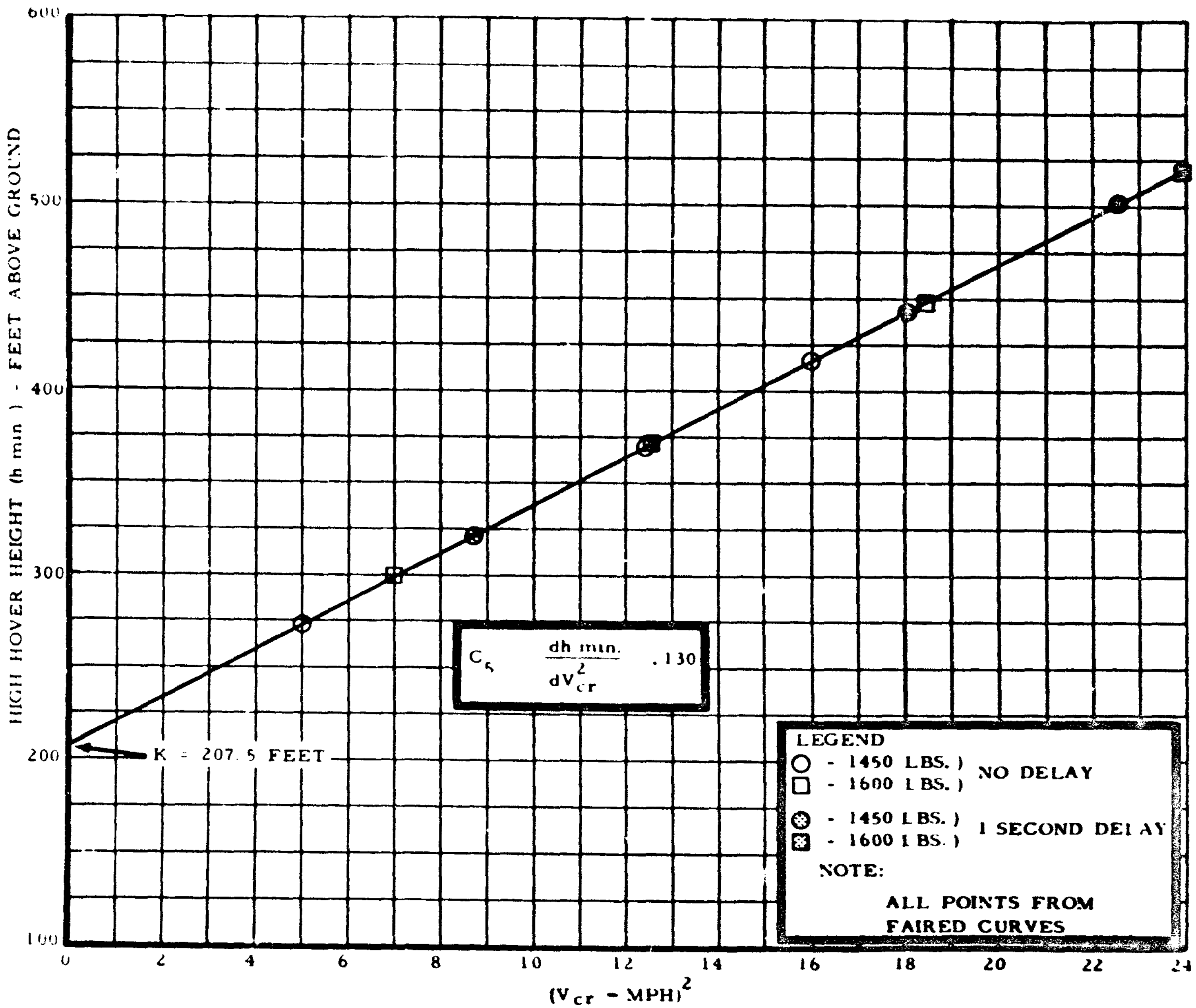


FIG. 16 HIGH HOVER HEIGHT (h_{min}) VERSUS SQUARE OF CRITICAL VELOCITY (V^2_{cr})

APPENDIX 1

TEST AIRCRAFT SPECIFICATIONS AND INSTRUMENTATION DETAILS

APPENDIX 1

TEST AIRCRAFT SPECIFICATIONS

Significant specifications of the test aircraft and its powerplant are as follows:

1. Powerplant: Lycoming Model HIO-360-A1A

    a. Horsepower rating - 180 HP to 3900feet

    b. RPM limitations - 2900 Maximum, 2700 Minimum

2. Weight, Gross:

    a. Maximum certified - 1670 pounds

3. Service ceiling:

    a. @ 1670 pounds - 14,000 feet

4. Hovering ceiling:

    a. @ 1670 pounds - 7700 feet - in ground effect

    b. @ 1670 pounds - 5300 feet - out of ground effect

5. Maximum speed:

    a. Sea level - 87 MPH - IAS

6. General data:

    a. Rotor diameter - 25.29 feet

    b. Rotor disk area - 503 square feet

    c. Rotor blade chord -,562 feet

    d. Blade twist - 8° washout

    e. Airfoil section - NACA .0015

    f. Number of blades - 3

    g. Solidity ratio - .0424

    h. Disc loading @ 1670 pounds - 3.32 pounds/feet^2

    i. Rotor inertia - 135.6 slug feet^2

    j. Rotor System Configuration - articulated

    k. Flapping Hinge Offset - 2.125 inches

TEST AIRCRAFT SPECIFICATIONS CONTINUED

l. Engine to main rotor ratio - 6:1

m. Rotor speed limitations - 530 RPM Maximum, 400 RPM Minimum

TEST INSTRUMENTATION

A brief description of the test instrumentation utilized for this flight test program is as follows:

1. Airborne

The airborne quantitative information measured was:

a. Airspeed

b. Altitude

c. Rotor rpm

d. Engine rpm

e. Collective Stick Position

f. Cyclic Stick Position

g. Acceleration (vertical)

h. Fuselage Attitude (pitch)

i. Angular Velocity (pitch)

j. Height (radar altimeter)

k. Instantaneous Vertical Velocity

l. Throttle Position

This information was recorded on an oscillograph. Figure 1-1 shows the installation of the recording equipment and some of the basic instrumentation within the cabin of the aircraft. Figure 1-2 points out the location of some of the airframe instrumentation and exterior accessories utilized for the control and accomplishment of the test.

2. Ground

Space position equipment utilized for tracking the aircraft is shown in Figs. 1-3a and 1-3b. Two photographic flight path analyzers were utilized so as to augment each other's photographic capability. The phototheodolite flight path analyzer, because of its limited height coverage was used specifically for the low height-over-the-ground tests that involved primarily vertical movement of the helicopter. The Fairchild flight path analyzer was used primarily for flights that involved high heights-over-the-ground and relatively large horizontal helicopter movements. A sample photographic plate is shown in Fig. 1-4.

Meteorological equipment utilized for recording atmospheric conditions during the flight tests is shown in Figs. 1-5a and 1-5b.

The wind speed and direction recorder was a battery-operated portable field instrument capable of recording wind speed from 3/4 mph to 10 mph and wind directions throughout 354 degree azimuth. The equipment's low threshold and high sensitivity permitted spontaneous and accurate measurement of small scale fluctuations in wind direction and velocity.

For measuring atmospheric pressure, a portable precision aneroid barometer with an indicating range capability of 1030 to 540 millibars was utilized. The versatility and high accuracy of the instrument made it ideal for use at all of the selected test sites.

Wet and dry bulb air temperatures were measured with a portable electrically aspirated psychrometer. These measurements together with accurate pressure indications were the basis for accurate determination of the density altitude at the time of testing.

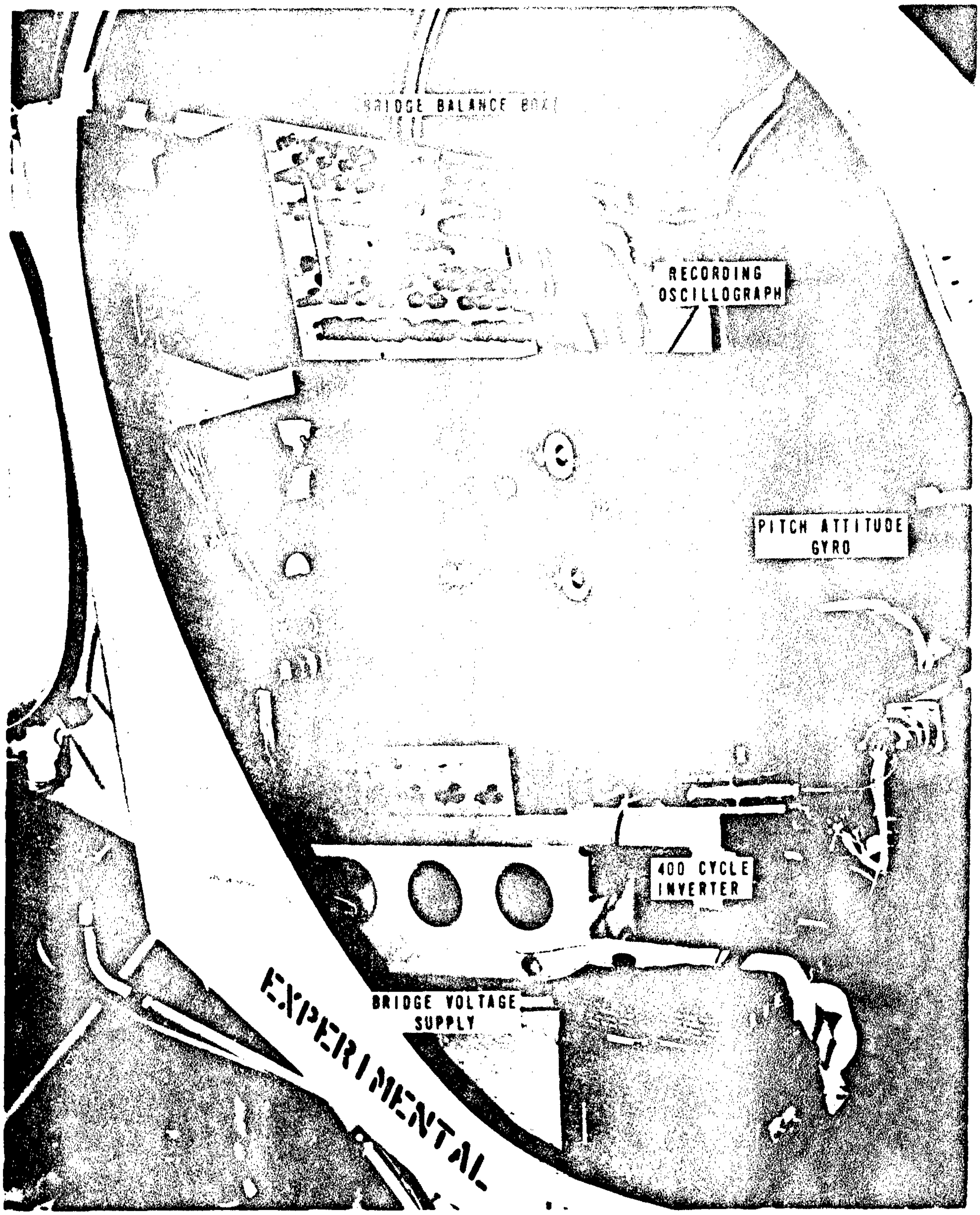
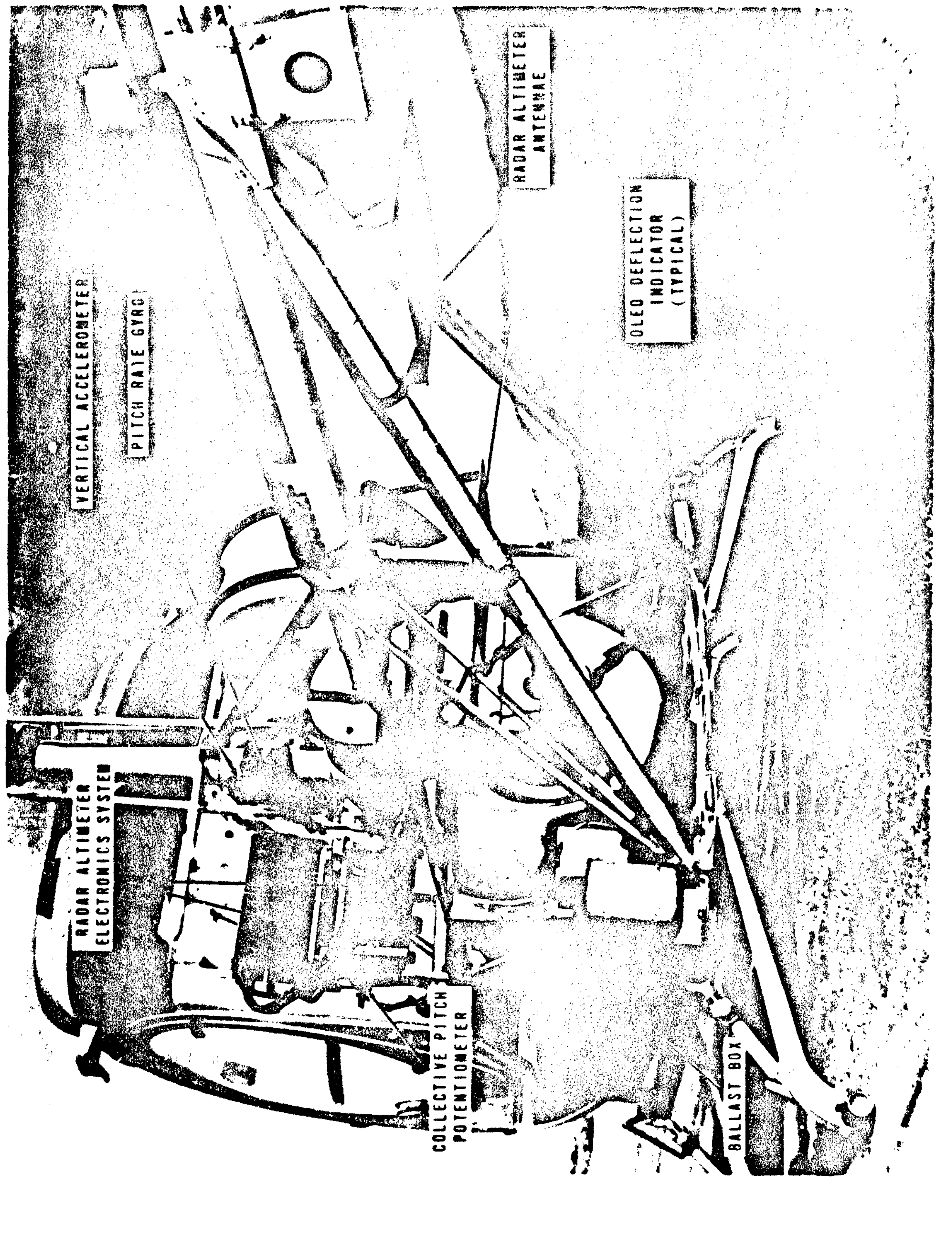
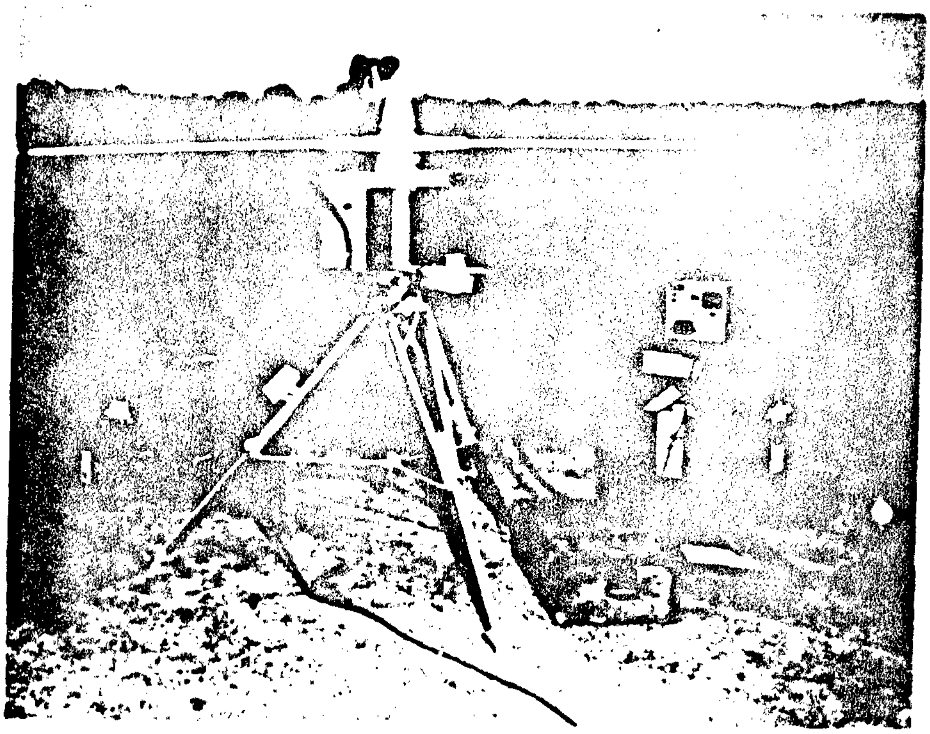


FIG. 1-1 AIRBORNE INSTRUMENTATION


RADAR ALTIMETER ANTENNAE
OLEO DEFLECTION INDICATOR (TYPICAL)
VERTICAL ACCELEROMETER
PITCH RATE GYRO
RADAR ALTIMETER ELECTRONICS SYSTEM
COLLECTIVE PITCH POTENTIOMETER
BALLAST BOX

A. Phototheodolite Flight Path Analyzer
(Motion Picture)



B. Fairchild Flight Path Analyzer
(Still Picture)

FIG. 1-3 SPACE POSITIONING EQUIPMENT

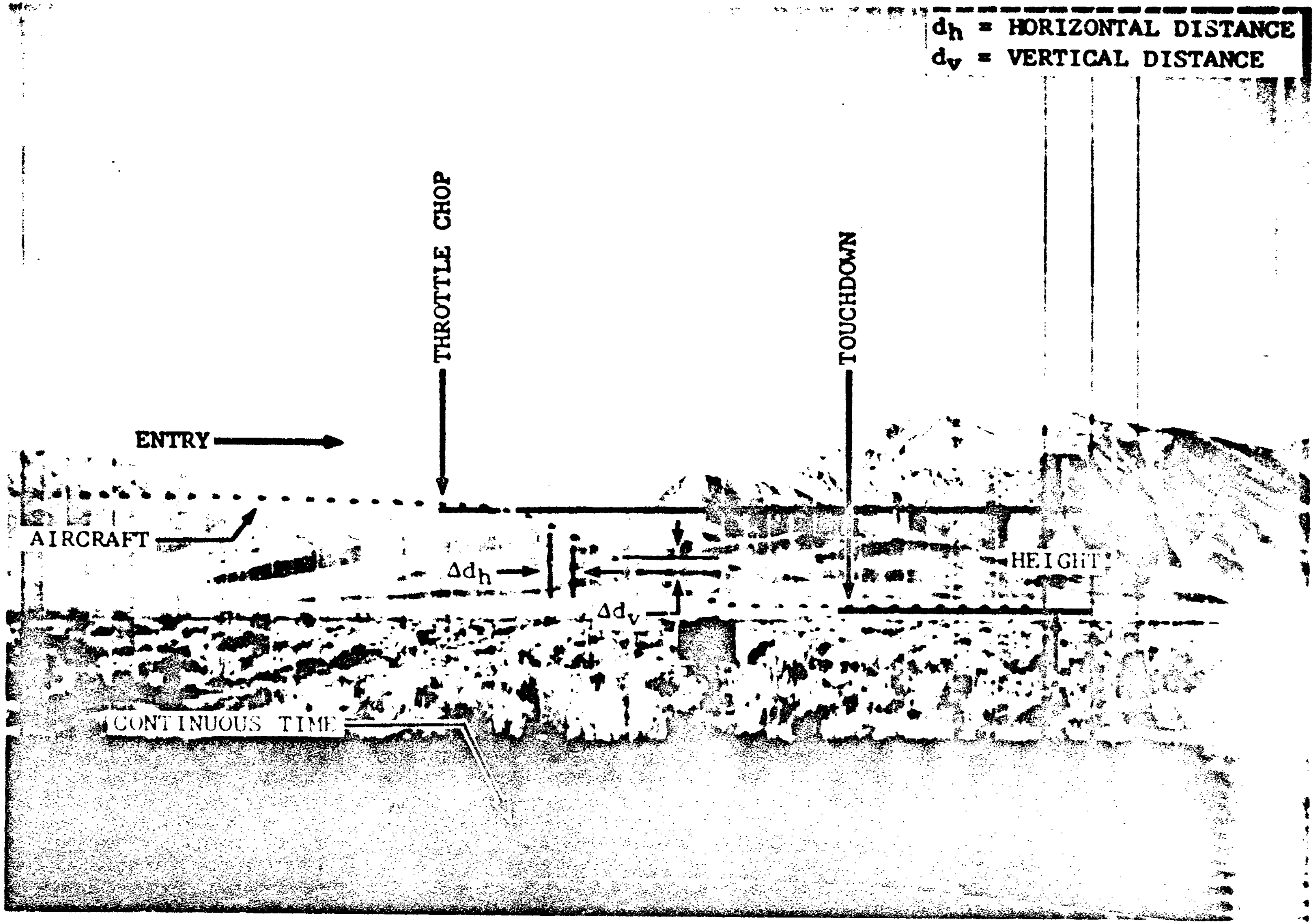
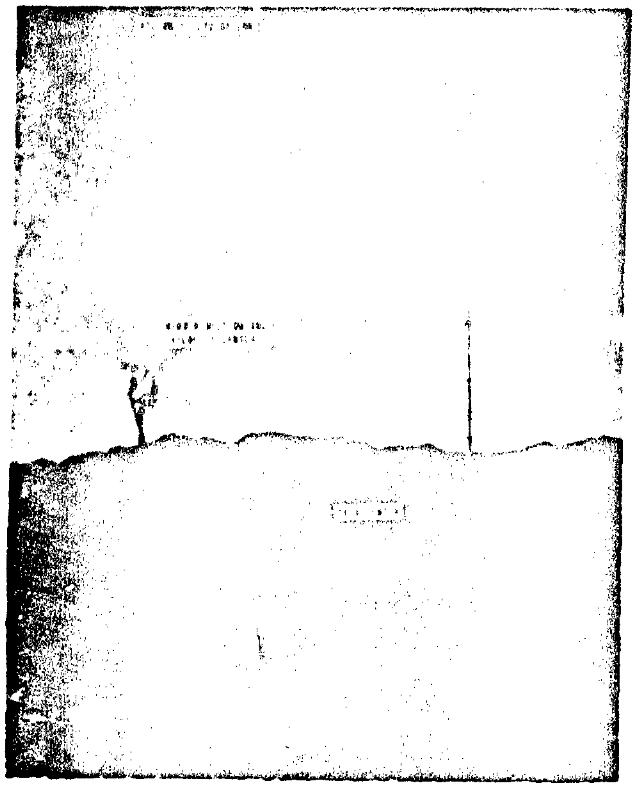
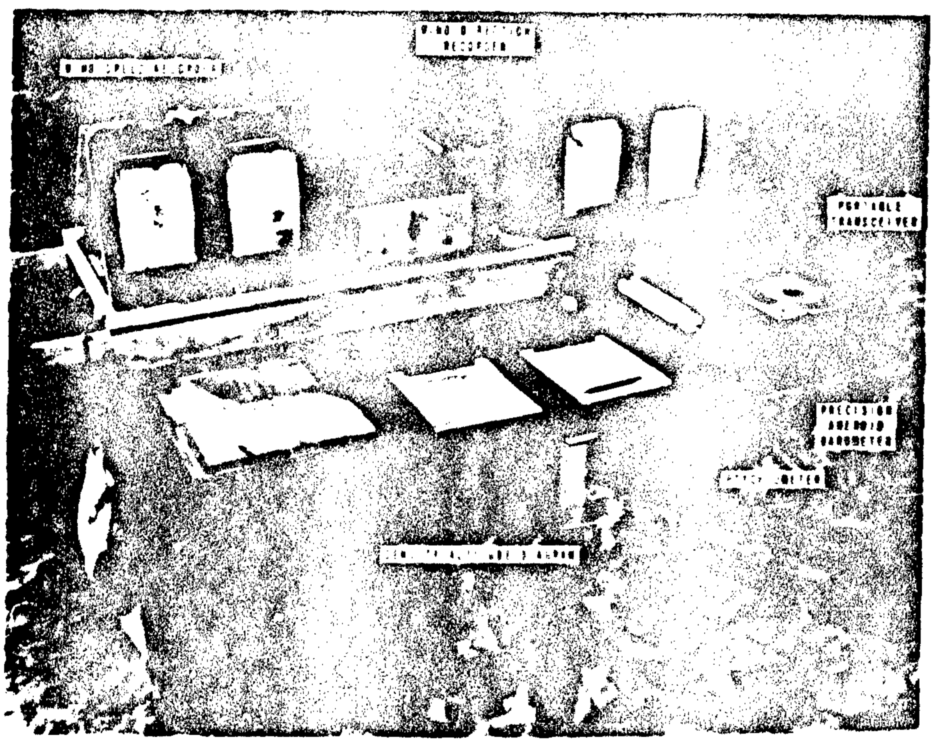


FIG. 1-4 TYPICAL FLIGHT PATH PHOTOGRAPH



A. Wind Speed and Direction Sensors



B. Data Center Measuring and Recording Equipment

FIG. 1-5 METEOROLOGICAL EQUIPMENT

APPENDIX 2

PILOT'S COMMENTS

APPENDIX 2

PILOT'S COMMENTS

Introduction

The test pilot's comments relative to the various techniques employed in executing the simulated power failure landings, and his comments concerning the characteristics of the helicopter with respect to the project are included herein for a better understanding of the material contained in this report. The comments are presented in two basic forms. First, in the form of general comments as prepared by the pilot from an overall point of view, and second, in the form of questions and answers concerning specific areas of interest.

General

Final review of pilot techniques utilized, in the determination of maximum data points only for the height-velocity project, reveal that for each major area of the diagram a different technique is required. The determination of whether a point is maximum can be arrived at, in most cases, by determining if proper entry conditions were adhered to, such as good control of airspeed maintained, full utilization of cyclic flare, and proper and maximum use of collective pitch resulting in a touchdown landing that meets the desired criteria established for the test with regard to impact velocity. The areas of h_{min}, h_{max}, and the low boundary require variations to the above and a description of the techniques utilized in obtaining the maximum point in each area will be discussed below.

h_{min} - The accomplishment and determination of a maximum point from h_{min} is, in my opinion, the most difficult area encountered during the project. Obtaining the one second delay, which should be strictly adhered to for proper evaluation of the point, requires some concentration coupled with determining that it is a true hover condition and that the altitude is precisely maintained. The technique utilized in this area is to obtain the airspeed required for an effective flare, accomplish the flare as near the ground as possible, allowing only sufficient height above the ground to rotate to a level attitude and then utilize remaining collective pitch. This technique results in a lower impact velocity with regard to the test requirements, however the maximum point has been established. Utilization of any other technique with this aircraft would increase the impact velocity, however, h_{min} would also increase.

h_{max} - These points were obtained by some reduction of collective pitch following throttle chop and then increasing collective pitch to the full up position just prior to touchdown.

Lower Boundary - The establishment of a maximum point in this area was determined by impact velocity and rotor energy. In the low area of this boundary where airspeed and altitude are insufficient for a full effective flare, either a partial flare or none at all was used. Utilization of collective pitch also varies as to whether it can be completely reduced, partially reduced, or not reduced at all following throttle chop. The most critical data point from the standpoint of the pilot being able to utilize any type of technique to improve the condition occurs in the low altitude and low airspeed area. This flight regime of approximately ten feet and fifteen miles per hour is where airspeed available is insufficient to flare effectively and rotor inertia is insufficient to hold the aircraft through the longer glide path which is caused by the airspeed.

In review of all data points, rough data only, it is my opinion that the ability to obtain full utilization of a well coordinated cycl flare is the main determining factor in obtaining a maximum data point The proper application and utilization of full collective pitch certainly is a strong factor in the data point also, however, the proper and full utilization of collective pitch will not establish the maximum obtainable data point unless the maximum effective flare possible is obtained.

QUESTION AND ANSWER

1. Question -

Describe the loss of control at the high hover following throttle chop, both directional and pitching control.

Answer -

A. Directional control deteriorated in a ratio to the power required for hover (gross weights and density altitude) and the amount of delay utilized in lowering the collective pitch. Pedal application was considerable during the initial 100-150 feet of the dive that was required to regain airspeed.

B. Pitching control problems occurred only when the rotor RPM was allowed to deteriorate very low or the gross weight of the aircraft and the steep angle of dive did not permit a rapid buildup of rotor RPM prior to the flare.

2. Question -

Is the above effect more pronounced at 1600 lbs. than at 145(lbs. or vice-versa?

Answer -

The effect is more pronounced initially out of the hover cut at 1600 lbs., but becomes acceptable early in the dive. The 1450 lb. hover cut is marginally acceptable initially, however, some additional deterioration occurs during the early portion of the dive to regain airspeed.

3. Question -

Does it appear to be more serious at altitude or is it the same for a given height above the ground appropriate to the altitude?

Answer -

It is more serious with altitude which is probably due to the power required and higher rotor decay following throttle chop.

4. Question -

Under what conditions does the tendency to "fall thru" arise? That is, what transpires when the helicopter fails to respond to a flare?

Answer -

The perspective and feeling that the pilot gets when the helicopter is "falling thru the flare" is that either the sink rate was in excess of what he anticipated while higher above the ground, or that he is in a down-wind or down-draft condition. The pilot at this time is quite certain that the flare will not stop the rate of descent sufficiently and therefore he will attempt to level the aircraft and apply collective pitch prior to impact or initiate a power recovery, or both.

5. Question -

Does the failure to respond to a flare in arresting the descent have as an added factor, the reduction in ability to level out (pitching control) or are they separate factors?

Answer -

It appears that the problem in leveling out is the result of collective pitch being applied in the flare, thus reducing rotor RPM and encountering a partial loss in longitudinal controllability, as compared to operating with full rotor RPM until level.

6. Question -

In each of the various regimes of the H-V diagram, what seems to be the most important factor in achieving a minimum point on the diagram?

Answer -

A. h_{min} - Altitude in which to regain flare airspeed without resorting to an excessive dive angle. Directional control in some instances adds to the altitude required to accomplish this.

B. "Knee" - Altitude to regain flare airspeed and build up rotor RPM and the rapidity of movement required by the pilot.

C. Lower Boundary - If sufficient altitude is still available for a slight dive and flare then the pilot reaction and movement time is the most important factor. If altitude and airspeed is not available for flare then ground contact speed and proper use of remaining collective pitch is the important factor.

7. Question -

What is the best technique from high hover or near high hover? That is, does the rate of descent increase with an abrupt lowering of the pitch over that which would be achieved at a slower more steady pitch reduction?

Answer -

I found that the best technique was a rapid reduction of collective pitch either following a no-delay or one-second delay throttle chop. The high hover rotor decay rate is a direct function of power required and while it might appear that initial descent is slower with a slow reduction in collective pitch, the rotor RPM has to be regained eventually by the use of airspeed and flare.

8. Question -

What is the effect on control of these pitch reduction techniques?

Answer -

A one-second delay throttle cut followed by a slow collective pitch reduction will bring rotor RPM to minimum red line or below, and thus result in some of the directional and longitudinal control problems experienced.

9. Question -

With respect to the upper boundary, how does the one-second delay affect the rotor speed decay?

Answer -

Proportionate to the collective pitch position required for the power utilized in stabilizing on the particular point.

10. Question -

Does this delay contribute markedly to the loss of control discussed above?

Answer -

Proportionate.

11. Question -

What are the factors in the one-second delay which contribute to the marked increase in entry speed required to effect a landing?

Answer -

Loss of rotor RPM, some increase in airspeed required to regain the additional loss of rotor RPM versus no-delay, and probably failure of the pilot to react instantly to desirable cyclic movements as some of his concentration is devoted to insuring that the delay time is quite precise. These would be fraction of a second movements and decisions, however, they could affect the determination of the maximum point.

12. Question -

What was most difficult about obtaining high hover data (h min. points)?

Answer -

A. Unstable air conditions is the prime factor.

B. Secondary, would be the stabilizing of the hover condition. I attempted to give consistent power conditions for the throttle chop, the radar altimeter made this a very difficult area. This is a condition that should be read very closely on the oscillograph (for both projects) because unless the pilot is conscientious to the program, he could make the area of h_{min} look better than it is by being in a high power condition initially and then reduce collective slightly just prior to the cut or at the cut.

C. The decision at which time and position to abort the autorotation or decide that you might make it if everything comes out perfectly.

13. Question -

What was the criteria used by you to determine if a point was maximum at the time of execution; i.e., impact, control response and time available, rate of sink, aircraft shudder, directional instability, etc.?

Answer -

You answered it! Some particular point on the H-V diagram would have one of these factors associated with the determination of a maximum point. The very least consideration would be given to aircraft shudder. The majority of the maximum points were determined by maximum utilization of flare, rotor energy and impact.

14. Question -

Did this criteria vary with the point being attempted; i.e., upper boundary, lower boundary, "knee"?

Answer -

Yes. Attempt was made, however, to utilize full benefit of rotor energy and maximum impact in the determination of all points if at all possible.

15. Question -

What is your opinion relative to the effects of wind on the various areas of the diagram determination, particularly as it concerns the 269B?

Answer -

A. In the area of h_{min} the wind factor is very important. If it is down-wind at the throttle chop point, it affects the attitude at the cut and also appears to add to the pilot's impression of an accelerated sink condition. The wind condition at ground level, unless abnormal, would not appreciably affect the h_{min} condition as this point appears to be greatly affected by dive angle, time to regain airspeed, sufficient flare to build up rotor RPM, and time required to level aircraft following flare.

B. Head wind benefits the diagram in the area of the "knee" and the lower boundary. I am not certain, however, that a quartering wind to the direction of a landing is exactly the same relationship that would result from a wind vector problem. I recall having difficulty with some points which had a plus wind component and yet were of the crosswind or quartering wind type.

C. Cross or gusty wind conditions definitely affected the very slow airspeed points as it resulted in considerable pedal applications in order to stabilize on a given condition for the time required to fly from the radio link actuation to the desired point of throttle chop.

16. Question -

Do you believe that any other landing or touchdown attitude would materially affect the size or shape of the H-V curve?

Answer -

It is conceivable that a nose high landing might reduce the size or change the shape of the H-V curve, however, some of the touchdowns were of a fairly high impact type and I am positive that these would have still been hard with the nose high technique and thus result in some type of failure. In the area of the lower boundary (air taxi) this technique would definitely not be utilized, as no benefit could be derived from a flare at such a low airspeed, and sufficient rotor energy to cushion a nose high landing does not exist at that time.

17. Question -

Did you experience any difficulty in adjusting to the various density altitudes? Did a large change in altitude affect your performance initially at the new altitude?

Answer -

A. Yes. I initially did not believe that the H-V curve at 7000 feet would be as completely defined as it was. I felt that the high entry speeds would be prohibitive to obtaining many points. It was my belief that the sea level testing would not represent as much of a reduction in airspeed and altitude as it eventually did.

B. Yes. Obtaining the mental preparation for operating in an area that had not previously been conducted under normal certification programs resulted in a cautious approach and some pre-planning of the expected escape path in the event an unforeseen problem area arose.

C. The most difficult area to adjust to, however, was the unstable air conditions that existed during the repeat flights at Bishop and the high hover points at Fresno. In many instances, points became more difficult in these conditions than they were when previously completed from lower altitudes and slower airspeeds.

APPENDIX 3

SUMMARY OF HEIGHT-VELOCITY DIAGRAM FLIGHT TEST DATA

SUMMARY OF HEIGHT VELOCITY DIAGRAM FLIGHT TEST DATA

FLT. NO.	RUN NO.	DATE 1964	AIRCRAFT GROSS WT. (LBS)	DENSITY ALTITUDE (FEET)	WIND COMPONENT (MPH)	THROTTLE CHOP HEIGHT (FEET)	THROTTLE CHOP V_{cal} (MPH)	LANDING V_{cal} (MPH)	LANDING ACC (g's)	TIME DELAY (SEC)	NOTES
19	2	10/13	1451	4800	+3.1	72.0	33.1	16.4	3.45	0.47	(3)
19	5	10/13	1438	4850	+2.9	49.0	32.3	22.9	2.09	0.19	
19	6	10/13	1435	4950	+2.5	43.5	30.5	16.2	2.01	0.21	
19	8	10/13	1451	5200	+3.5	38.0	30.6	13.8	2.80	0.19	
19	11	10/13	1455	5350	+1.4	192.0	25.9	21.0	2.65	0.52	
19	12	10/13	1451	5400	+2.1	196.5	23.7	19.9	2.54	UNK	(2)
19	13	10/13	1449	5400	+2.6	241.0	22.4	20.7	1.65	0.20	
19	14	10/13	1447	5400	-0.4	307.0	-0.4	17.4	1.83	0.19	
19	20	10/13	1451	5600	+2.6	14.2	0	UNK	2.62	0.15	(1)
19	21	10/13	1450	5600	+1.3	11.6	1.2	2.9	2.91	0.17	(1)
19	22	10/13	1438	5750	+1.5	18.0	13.7	10.7	3.53	0.47	(3)
20	17	10/14	1586	5300	+2.7	39[illegible].0	8.3	14.6	UNK	0.06	(2)
21	3	10/15	1598	4500	+1.3	150.0	42.0	17.1	2.20	0.06	
21	6	10/15	1609	4700	+3.6	200.0	36.8	19.2	2.14	0.11	
21	9	10/15	1598	4850	+4.0	251.0	31.9	15.6	1.87	0.14	
22	3	10/16	1600	4300	+2.6	101.0	42.9	18.7	2.87	0.15	
22	4	10/16	1597	4300	+1.9	63.5	44.9	18.8	2.50	0.14	
22	7	10/16	1594	4500	+3.2	306.0	26.6	12.1	1.65	0.14	
22	10	10/16	1602	5150	+1.4	314.0	29.2	15.9	1.59	0.15	
22	11	10/16	1599	5200	+0.7	337.5	20.6	12.5	1.74	0.15	
22	13	10/16	1601	5300	+0.9	394.0	16.5	11.4	2.32	0.07	
22	15	10/16	1600	5450	-2.6	445.0	-2.4	13.3	1.56	0.12	
25	10	10/20	1596	4900	+4.7	97.5	51.9	20.2	2.60	1.18	(3)
25	11	10/20	1592	4950	+3.1	278.0	36.8	14.8	1.67	1.47	
25	12	10/20	1590	5000	+2.8	189.0	44.8	[illegible]	1.59	1.04	
25	13	10/20	1608	5100	+4.2	396.0	23.5	12.3	1.87	1.40	
25	14	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	13.0	1.69	1.12	
25	15	10/20	1598	5200	+4.3	338.0	29.4	11.0	1.70	0.77	
26	10	10/21	1448	4500	+1.2	290.0	20.7	13.3	2.10	1.08	
26	12	10/21	1446	5225	+1.0	15.0	29.5	UNK	1.85	0.27	(1)
26	15	10/21	1451	5650	-0.1	99.0	43.3	17.9	2.04	0.87	
28	2	10/23	1451	5000	+4.6	93.5	35.5	28.6	2.45	0.26	
28	5	10/23	1451	5250	+3.1	108.5	38.1	18.6	2.29	0.13	
28	8	10/23	1450	5300	+4.7	227.5	23.3	19.7	1.98	0.12	
28	10	10/23	1455	5400	+3.9	346.0	6.4	19.1	1.83	0.19	
28	11	10/23	1452	5350	+4.8	323.0	5.7	18.1	1.56	0.13	
28	13	10/23	1447	5400	+4.2	412.0	8.5	17.5	1.51	0.66	(2)
28	14	10/23	1453	5500	+3.3	415.0	3.0	11.5	1.41	UNK	(2)
28	15	10/23	1[illegible]46	5500	+1.2	186.0	36.4	30.7	3.46	1.00	(3)
29	3	10/25	1599	4700	+0.8	40.4	40.5	16.6	[illegible].69	0.14	
29	8	10/25	1599	4900	+3.3	15.0	31.9	18.5	2.93	0.16	
29	10	10/25	1594	5000	+5.0	10.0	22.8	22.0	2.16	0.22	
29	11	10/25	1608	5100	-0.8	459.0	+0.7	14.8	1.63	0.27	

FLT. NO.	RUN NO.	DATE 1964	AIRCRAFT GROSS WT. (LBS)	DENSITY ALTITUDE (FEET)	WIND COMPONENT (MPH)	THROTTLE CHOP HEIGHT (FEET)	THROTTLE CHOP V_{cm} (MPH)	LANDING V_{cm} (MPH)	LANDING ACC. (g's)	TIME DELAY (SEC)
29	13	10/25	1603	5225	-1.9	484.0	-0.37	11.4	1.53	0.94
29	14	10/25	1600	5250	-0.8	478.0	0.6	11.3	1.54	0.79
29	15	10/25	1605	5275	+1.5	432.0	4.6	14.6	1.73	0.18
29	19	10/25	1605	5300	+0.7	10.5	0	UNK	2.60	0.49
29	21	10/25	1600	5350	-2.0	9.1	10.0	UNK	1.94	0.16
30	2	10/25	1455	5700	+0.8	325.0	2.0	22.1	1.60	0.13
30	4	10/25	1447	5800	0	278.0	18.0	10.3	2.06	0.15
35	5	10/31	1445	6550	+2.5	12.4	2.3	2.3	2.58	0.26
35	6	10/31	1444	6650	+2.5	12.0	2.3	2.3	2.80	0.25
35	9	10/31	1447	6750	+2.6	11.2	12.1	11.9	2.01	0.17
35	11	10/31	1443	6750	+2.7	11.6	18.9	17.1	2.33	0.16
36	7	11/3	1449	6550	+2.5	308.6	20.5	UNK	1.44	0.13
36	9	11/3	1444	6600	+1.7	187.5	32.4	UNK	1.78	0.06
36	14	11/3	1456	7100	-0.7	150.0	40.3	19.1	2.11	0.15
36	16	11/3	1448	7200	-0.9	430.0	0.27	9.6	1.51	0.19
36	18	11/3	1450	7400	+1.4	510.0	2.5	11.1	1.54	0.82
37	2	11/4	1452	6550	-3.9	195.0	33.8	18.1	2.37	0.1
37	4	11/4	1455	6600	-0.2	265.0	24.2	17.8	1.49	0.53
37	5	11/4	1452	6600	+4.3	354.0	16.8	15.0	1.55	0.19
37	6	11/4	1448	6600	+0.9	106.0	43.3	19.4	2.43	0.16
37	9	11/4	1446	6650	+1.8	51.0	36.8	18.7	2.49	0.14
37	12	11/4	1450	6900	+2.3	19.0	30.9	16.1	2.37	0.10
37	14	11/4	1445	7000	+4.1	76.0	38.5	19.6	2.11	0.14
37	18	11/4	1445	7100	+1.8	95.5	45.4	25.4	2.46	1.00
37	20	11/4	1451	7250	+3.3	375.0	7.0	13.9	1.48	0.21
37	23	11/4	1451	7300	+1.8	312.0	29.4	15.1	1.54	1.10
39	2	11/6	1450	4800	+2.6	152.0	29.3	20.8	2.30	0.17
39	8	11/6	1453	4950	+2.6	246.0	22.9	17.4	1.80	0.15
40	2	11/7	1451	4800	+3.7	13.5	14.0	15.5	2.50	0.29
41	2	11/11	1454	3900	+3.0	21.7	24.4	19.2	1.81	0.18
41	3	11/11	1451	3950	+1.4	28.5	19.8	23.8	2.03	0.13
41	5	11/11	1450	4150	-0.9	252.0	13.9	12.1	1.75	0.15
41	6	11/11	1447	4250	+1.4	251.0	11.5	14.1	1.72	0.10
41	8	11/11	1450	4450	+3.1	143.0	24.9	23.3	2.41	0.07
41	11	11/11	1443	4400	+1.0	321.0	2.5	14.8	1.31	0.11
46	10	11/17	1448	-450	+3.6	100.0	23.6	13.4	2.26	0.14
46	13	11/17	1454	-300	-1.5	263.0	0.2	11.4	1.48	0.12
46	14	11/17	1450	-350	-0.9	270.0	3.9	9.4	1.54	0.10
46	15	11/17	1447	-350	-1.4	255.0	4.9	10.8	1.62	0.12
46	16	11/17	1445	-400	+2.5	248.0	5.4	13.4	2.03	0.12
46	19	11/17	1446	-350	+0.2	72.0	22.3	13.7	1.78	0.13
46	24	11/17	1454	-350	+1.9	19.3	0	UNK	3.27	0.28
46	27	11/17	1449	-350	+2.2	26.0	21.2	UNK	1.73	0.15

FLT. NO.	RUN NO.	DATE 1964	AIRCRAFT GROSS WT. (LBS)	DENSITY ALTITUDE (FEET)	WIND COMPONENT (MPH)	THROTTLE CHOP HEIGHT (FEET)	THROTTLE CHOP $V_{(CA)}$ (MPH)	LANDING $V_{(CA)}$ (MPH)	LANDING ACC (g's)	TIME DELAY (SEC)	NOTES
48	4	11/19	1449	-450	+2.2	30.3	13.3	9.9	1.97	0.08	
48	11	11/19	1443	-400	+4.0	48.2	22.4	UNK	2.03	0.10	(1)
49	4	11/19	1604	-300	+2.50	16.0	3.3	4.1	2.72	0.20	
49	7	11/19	1596	-300	-0.26	25.3	11.4	11.4	3.10	0.14	
49	10	11/19	1599	-400	+0.58	26.7	22.3	15.7	2.41	0.19	
49	13	11/19	1604	-250	+1.6	53.6	26.3	UNK	2.81	0.14	(1)
50	3	11/20	1448	-700	+2.3	49.0	26.3	19.1	1.93	0.16	
50	6	11/20	1447	-650	+1.2	81.0	22.3	18.4	2.63	0.17	
50	7	11/20	1445	-650	-0.9	201.0	10.4	11.4	1.97	0.09	
50	8	11/20	1442	-550	+1.1	200.0	11.4	13.2	1.78	0.13	
50	10	11/20	1451	-450	+2.6	230.0	10.5	16.9	1.39	0.05	
50	16	11/20	1449	-350	+2.7	310.0	3.0	17.7	1.41	0.86	
50	19	11/20	1451	-450	+3.2	150.0	24.7	16.9	1.55	0.14	
53	8	11/23	1604	-300	-2.0	100.0	25.6	17.3	2.72	0.18	
54	3	11/24	1596	+150	+1.7	198.0	12.3	20.0	1.94	0.14	
56	4	11/30	1600	-550	+4.5	72.0	26.3	23.6	2.47	0.11	
56	7	11/30	1601	-500	+1.9	153.0	22.6	18.4	2.80	0.13	
56	10	11/30	1605	-350	+1.6	243.0	5.8	12.7	2.11	0.11	
56	11	11/30	1602	-250	-3.0	250.0	10.6	18.4	1.41	0.08	
56	13	11/30	1604	-50	+4.1	290.0	4.9	19.4	1.81	0.12	
56	17	11/30	1596	-50	+3.9	142.0	32.3	22.9	2.70	0.97	
57	1	12/2	1607	+100	+1.9	97.0	37.3	19.6	3.25	1.02	
58	2	12/2	1453	+400	+0.4	146.0	20.0	15.0	2.53	0.11	
58	3	12/2	1450	+400	-2.5	144.0	16.4	18.7	2.32	0.14	
58	4	12/2	1454	+500	+2.4	55.0	25.6	17.6	2.26	0.08	
[illegible]	5	12/2	1451	+400	+2.2	31.0	21.9	20.6	2.32	0.20	
58	6	12/2	1450	+500	-0.8	19.5	8.1	9.6	2.20	0.09	
59	3	12/4	1447	-50	+1.3	104.0	30.5	15.5	2.02	0.90	
59	4	12/4	1454	-50	+1.6	98.0	29.8	22.0	2.50	0.96	
59	5	12/4	1451	-50	+0.95	193.0	21.0	20.2	1.93	0.80	
59	6	12/4	1457	-50	+1.4	200.0	18.6	13.9	2.52	0.87	
59	9	12/4	1453	-50	+2.9	253.0	11.1	17.3	1.55	0.80	
59	10	12/4	1450	-50	+2.85	245.0	11.4	19.3	1.72	1.10	
61	3	12/6	595	-1000	+1.8	[illegible]	16.5	22.7	1.31	1.00	
61	4	12/6	1601	-950	+1.9	262.0	18.6	20.5	1.62	0.91	
61	5	12/6	1598	-900	+2.9	252.0	17.3	21.6	1.36	1.00	
62	1	12/6	1452	-100	+2.0	19.0	2.0	3.6	3.37	0.24	

Notes
1. Data obtained from Oscillograph only
2. Data obtained from Photographic Analysis only
3. Rear cross tube yielded